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10. Responsible Manager	Jerry King	[signature] for Jerry King	03/22/04

11. Remarks

This Analysis supercedes the previous Calculation CAL-WIS-PA-000001 Rev 01.

Changes to the original calculation are so numerous that the use of change bars was not implemented.

The previous TBVs entered on that Calculation, namely TBV-4583 and TBV-4582 are no longer relevant to this Analysis.

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ACRONYMS AND ABBREVIATIONS

BSC	Bechtel/SAIC LLC
CDF	cumulative distribution function
COTS	commercial off-the-shelf software
CRWMS M&O	Civilian Radioactive Waste Management System Management and Operations Contractor
DTN	data tracking number
FEPs	features, events, and processes
IED	Information Exchange Drawing
LA	License Application
PVHA	Probabilistic Volcanic Hazards Assessment
QA	quality assurance
TBV	to be verified
TDMS	Technical Data Management System
TSPA	Total System Performance Assessment
TSPA-LA	Total System Performance Assessment for the License Application
TSPA-SR	Total System Performance Assessment for the Site Recommendation
TWP	technical work plan
UTM	Universal Transverse Mercator projection
YMP	Yucca Mountain Project
YMRP	Yucca Mountain Review Plan

1. PURPOSE

The purpose of this scientific analysis report is to document calculations of the number of waste packages that could be damaged in a potential future igneous event through a repository at Yucca Mountain. The analyses include disruption from an intrusive igneous event and from an extrusive volcanic event. The conduct of activities described in this report is documented in the *Technical Work Plan: Igneous Activity Assessment for Disruptive Events*, (BSC 2003 [166289]). The technical work plan (TWP) states that this documentation will provide an update and revision to *Number of Waste Packages Hit by Igneous Intrusion* (CRWMS M&O 2000 [153097]). While this document does provide an update and revision to the calculation of the number of waste packages hit documented in (CRWMS M&O 2000 [153097]), the new document identifier associated with this document reflects the fact that this document was developed under the *Scientific Analyses* procedure (AP-SIII.9Q Rev1 ICN 3 [167992]) instead of the *Design Calculations and Analyses* procedure (AP-3.12Q, REV 2, ICN 1 [165022]).

This analysis supports the evaluation of the potential consequences of future igneous activity as part of the Yucca Mountain Repository Total System Performance Assessment (TSPA) for the License Application (LA). Igneous activity is a disruptive event that is included in the Total System Performance Assessment for the License Application (TSPA-LA) analyses. Two igneous activity scenarios are considered: (1) The Igneous Intrusion Groundwater Release scenario ("igneous intrusion" scenario, for short) considers the in-situ damage to (or failure of) waste packages that occurs if they are encapsulated or otherwise affected by magma as a result of an igneous intrusion, and (2) The Volcanic Eruption scenario depicts the direct release of radioactive waste due to a volcanic eruption that intersects the repository. An igneous intrusion is defined as the ascent of a basaltic dike or dike system (i.e., a set or swarm of multiple dikes comprising a single intrusive event) to repository level where it intersects drifts. Magma that does reach the surface from igneous activity is an eruption (or extrusive activity) (Jackson, 1997 [109119]). The objective of this analysis is to develop a probabilistic measure of the number of waste packages that could be affected by each of the two scenarios. This scientific analysis report provides part of the documentation that the Features, Events, and Processes (FEPs) 1.2.04.04.0A "Igneous Intrusion Interacts with EBS Components" and 1.2.04.06.0A "Eruptive Conduit to Surface Intersects Repository" (BSC 2002 [158966]) have been properly implemented into the TSPA-LA.

In addition, this scientific analysis report provides documentation (Attachment IV) that acceptance criteria described in the Yucca Mountain Review Plan, Final Report (NRC 2003 [163274]), Sections 2.2.1.3.2.3 and 2.2.1.3.10.3, respectively, have been addressed.

This analysis differs from the previous calculation (CRWMS M&O 2000 [153097])) in a number of important ways, as summarized in the list below:

- New input probabilities calculated in *Characterize Eruptive Processes at Yucca Mountain, Nevada.* (BSC 2003 [166407]) are used.
- New parameter distributions calculated in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [163769]) are used.

- New supporting information contained in *Dike/Drift Interactions* (BSC 2004 [167778]) is used.

- New repository footprint layout documented in Sections 4 and 6 is used.

- New assumptions for both scenarios are used.

- New calculation approaches for both scenarios are applied.

The new calculation approach towards igneous intrusion is a significant improvement over previous revisions, primarily because it can utilize a more comprehensive sampling of igneous parameters. Moreover, the approach is more explicit in its determination of actual intersections between dike and drift. Although the calculation approaches are different from before, they do not justify categorization as a "model" *per se*, as defined in AP-SIII.9Q Rev 1 ICN 3 [167992]. The approaches are easily replicated and verifiable by simple hand calculations. Therefore, these calculations qualify as "analyses" (by definition from the same reference source).

2. QUALITY ASSURANCE

This report does not provide information on natural or engineered barriers or their performance with regard to waste isolation or engineered features important to safety as defined in AP-2.22Q, *Classification Analyses and Maintenance of the Q-List* (OCRWM, 2003) [164786].

Development of this scientific analysis report and the supporting analyses has been determined to be subject to the Yucca Mountain Project's (YMP) quality assurance (QA) program (BSC 2003 [166289], Section 8.1, Work Package ADEM03). Approved QA procedures identified in the technical work plan (TWP) (BSC 2003, Section 4 [166289]) have been used to conduct and document the activities described in this scientific analysis report. The technical work plan also identifies the methods used to control the electronic management of data (BSC 2003, Section 8.4 [166289]).

Specific procedures followed are:

AP-3.15Q, Rev 4, ICN 3, [168061] *Managing Technical Product Inputs*

AP-SI.1Q, REV 5, ICN 2. [165023] *Software Management*.

AP-SIII.9Q, REV 1, ICN 3 [167992], *Scientific Analyses*

AP-SIII.3Q, Rev 2, ICN 1, [168062] *Submittal and Incorporation of Data/Technical Information to the Technical Data Management System*

3. USE OF COMPUTER SOFTWARE

This analysis uses two software packages, which reside in the Yucca Mountain Software Baseline. LHS, Version 2.51, STN 10205-2.51-00 [167794], is a FORTRAN code, which provides a method to simultaneously bin multiple parameter distributions for use by subsequent models or calculations. The Latin Hypercube Sampling technique is used for this binning method. This technique approximates the Monte Carlo method without missing representative distribution tail values. For this analysis, LHS was used to develop a distribution of realizations of the required input parameters. The parameterization is described in detail in Sections 4 and 6 of this report. LHS was used within its intended purposes and its range of validation. LHS was used within an OpenVMS AXP, ver. 7.3-1 operating system, on a DEC Alpha platform. The software was selected because it was suitable for the tasks of binning multiple parameter distributions and combining them.

DIRECT, Version 1.0, STN: 11121-1.0-00 [167795], is a geometric analysis package written within the Torque Game Engine (www.garagegames.com), which is a commercial open-source software development kit employing C++ coding and a separate scripting language. DIRECT was specifically built to incorporate binned probability distributions of igneous parameters into calculations of the numbers of waste packages hit for this analysis (specific to dike - repository intersections only). DIRECT was used within its intended purposes and its range of validation. DIRECT was used within a Windows 2000 operating system, on a Dell Precision 330 platform. The software was selected because it was suitable for the tasks of calculating intersections between igneous dikes and repository drifts.

This scientific analysis also uses Microsoft EXCEL 2000 (9.0.5121 SR-1) for the Windows 2000 operating system. Within EXCEL, only standard EXCEL functions have been used in the calculation. Electronic output files from EXCEL are included as Attachments I through III.

Finally for the base analyses, two additional commercial off-the-shelf (COTS) exempt (according to Section 2.1 of AP-SI.1Q, REV 5, ICN 2. [165023]) software products are used; Rhinoceros version 3.0 and MilkShape 3D. Rhinoceros is a computer-aided design (CAD) package that was used to help visualize and scale base unit geometry inputs that eventually were transformed to represent volcanic dikes and the repository drifts in DIRECT. MilkShape 3D is a general-purpose 3D geometry file format translator and pre-processor. MilkShape 3D was used to convert the unit Rhinoceros-generated geometry files into a format suitable for input to DIRECT.

For the alternate analyses, the exempt commercial-off-the-shelf (COTS) software package, MATHCAD (by MathSoft, version 2001i, service release 2) was employed as a starting point to develop the coefficients used in Equation 1. The coefficients were later modified by hand to improve the fit to measured data and to reduce the bias. The final coefficients are shown in Table 7.

Although the calculation approaches utilize a number of software packages, the approach does not qualify as a "model" per se, as defined in AP-SIII.9Q Rev 1 ICN 3 [167992]. The approaches are easily replicated and verifiable by simple hand calculations. Therefore, these calculations qualify as "analyses" (by definition from the same reference source).

All software programs were run using appropriate computer platforms and operating systems, as required by AP-SI.1Q, Rev 5, ICN 2 [165023].

4. INPUTS

This section identifies data, parameters, criteria, and codes and standards associated with the scientific analysis. Uncertainties in input data and parameters are addressed in Section 6.5.

4.1 DATA AND PARAMETERS

Table 1 summarizes the inputs and input sources used for this analysis. Conditional probabilities for dike length, azimuth angle, and number of eruptive centers (conduits) on a dike (DTN: LA0302BY831811.001 [162670]) are used as input to this analysis. The probabilities are conditional on the occurrence of intersections of the repository by a dike. The file consists of 4032 points in a parameter space for dike length and azimuth angle. The data cover angles from 0° (north) to 175° in 5° increments (south-southeast) and lengths from 0 km to 5.55 km in 0.05 km increments. Details of this analysis are discussed in BSC (2003, Section 6.5 [163769]). That analysis summarizes and builds upon the *Probabilistic Volcanic Hazards Assessment* (PVHA) *for Yucca Mountain, Nevada* (CRWMS M&O, 1996, [100116]), in which the interpretations of 10 members of an expert panel were used to compute a probability distribution of the annual frequency of intersection of a basaltic dike or dike set with the repository footprint. The analysis assumes an origin for the igneous event (also called a volcanic event) and a dike with a given length and direction extending away from the origin. Points of origin have been used throughout the region around the repository based on the PVHA experts' interpretations. This input information is used in the calculations for the number of waste packages hit for both the Igneous Intrusion scenario (Section 6.3) and the Volcanic Eruption scenario (Section 6.4).

The report *Characterize Framework for Igneous Activity at Yucca Mountain* (BSC 2003, Table 19 [163769]) develops the final composite conditional probability distribution for number of eruptive centers. The data source for this information is DTN# LA0307BY831811.001 [164713]. That distribution is used as input to this calculation for determining the cumulative distribution function (CDF) for number of waste packages hit, given a maximum of 13 eruptive centers associated with a volcanic event.

Probabilities (as opposed to conditional probabilities described earlier) for the distribution of dike azimuth angles are also developed in the same analysis report, highlighted by Figure 22 of that report, and the pertinent section shown in Figure 3 of this report. The data source for this information is DTN # LA0303BY831811.001 [163985].

Repository Design Input Information is taken from several Information Exchange Drawings (IED). The IED: 800-IED-WIS0-00101-000-00Ab [164476], Figure 1, provides information on the underground layout configuration. The IED: 800-IED-WIS0-00103-000-00Ab [164491], Figure 2 and Table 8, provides information on the underground layout configuration and the repository areas, respectively. Table 2 of the IED: 800-IED-WIS0-00101-000-00Ab [164476], provides information on the UTM coordinates of each emplacement drift endpoint. This information is used to determine the lengths of each emplacement drift and to compute the average drift azimuth angle of 72 degrees.

Average spacing between drifts and drift diameter was taken from IED: 800-IED-MGR0-00201-000-00A, from the table labeled "Thermal Inputs for Supporting TSPA-LA" (BSC 2004 [167040]). Information on the expected total number of waste packages was taken from the IED: 800-IED-WIS0-00202-000-00B Table 11, (BSC 2004 [167207]). This information was used along with knowledge on each emplacement drift length to estimate the number of waste packages per drift.

Probabilities for dike spacing, number of dikes in a swarm, and eruptive conduit diameter are taken from DTN: LA0311DK831811.001 [166301]. The two latter probabilities have been transformed into CDFs. The CDF for conduit diameter is used in the calculations for the number of waste packages hit for the Volcanic Eruption scenario (Section 6.4). The CDF distributions for number of dikes in a swarm are used in the calculation for number of waste packages hit for the Igneous Intrusion Scenario (Section 6.3). Dike spacing probabilities are assigned by an algorithm that honors the probability distributions for each realization.

Table 1. Summary of Calculation Inputs

Input Information	Source for Input Information (including DTN or IED #)	Value
1. Final composite conditional probability distribution for number of conduits (eruptive centers) intersecting repository	DTN # LA0307BY831811.001 [164713] File: PECDIST-LA.xls, worksheet "table 19", Column I	Tabular Distribution
2. Marginal distribution of dike azimuth angles	DTN # LA0303BY831811.001 [163985] File: MLA-AZM.CDF	Graphical and tabular representation of Distribution
3. Conditional probabilities for dike length, dike azimuth angle, and number of conduits on a dike	DTN # LA0302BY831811.001 [162670] File: CCSM-LA.CMP	Tabular Distribution
4. Drift layout	IED: 800-IED-WIS0-00101-000-00Ab [164476] Figure 1 and 800-IED-WIS0-00103-000-00Ab Figure 2 [164491]	Graphical
5. Repository areas (active)	IED: 800-IED-WIS0-00103-000-00Ab Table 8 [164491]	table of values total = 5,419,074 sq. meters
6. Drift coordinates	IED: 800-IED-WIS0-00101-000-00Ab [164476] Table 2	table of values
7. Drift spacing and diameter	IED: 800-IED-MGR0-00201-000-00a Table labeled "Thermal Inputs for Supporting TSPA-LA" [167040]	81 m spacing 5.5 m diameter
8. Planned total # of waste packages	IED: 800-IED-WIS0-00202-000-00B Table 11, [167207]	11,184
9. Total number of active (non-contingency drifts)	IED: 800-IED-WIS0-00103-000-00Ab [164491] Figure 2	96
10. Maximum dike thickness	DTN # LA0311DK831811.001 [166301]	95^{th} percentile = 4.5 m
11. Number of dikes in a swarm (truncated log-normal distribution)	DTN # LA0311DK831811.001 [166301]	minimum = 1. mode = 3. 95^{th} percentile = 6
12. conduit diameter (triangular distribution)	DTN # LA0311DK831811.001 [166301]	minimum = 4.5 m. mode = 50 m. maximum = 150 m.
13. Dike spacing within a swarm (random uniform distribution)	DTN # LA0311DK831811.001 [166301]	min=100 m; max=690 m

4.2 CRITERIA

The general requirements to be satisfied by the performance assessment for a license application are stated in 10 CFR 63.114. [156605] Technical requirements to be satisfied by the TSPA are identified in the *Project Requirements Document* (Canori and Leitner 2003 [166275]). The acceptance criteria that will be used by the Nuclear Regulatory Commission (NRC) to determine whether the technical requirements have been met are identified in the *Yucca Mountain Review Plan, Final Report* (YMRP; NRC 2003 [163274]). Due to an update to and reinterpretation of the *Yucca Mountain Review Plan criteria* since the TWP, additional acceptance criteria are identified. This report constitutes a sub-component of the TSPA, and the pertinent requirements and criteria for this report are summarized in Table 2.

Table 2. Project Requirements for this Scientific Analysis Report

Requirement Number	Title	10 CFR 63 link	YMRP Acceptance Criteria
PRD-002/T-015 [166275]	Requirements for Performance Assessment	10 CFR 63.114 [156605]	2.2.1.3.2.3, 2.2.1.3.10.3 [163274]

The Yucca Mountain Review Plan (NRC 2003 [163274] acceptance criteria associated with the integrated subissue of Mechanical Disruption of Engineered Barriers are intended to ensure that the requirements at 10 CFR 63.114(a)-(c) and (e)-(g) have been met. Descriptions of information in this report that addresses the acceptance criteria associated with the integrated sub-issue of Mechanical Disruption of Engineered Barriers (NRC 2003 [163274], Section 2.2.1.3.2.3) are provided in Attachment IV.

Similarly, Yucca Mountain Review Plan acceptance criteria associated with the integrated sub-issue of *Volcanic Disruption of Waste Packages* are intended to ensure that the requirements at 10 CFR 63.114(a)-(c) and (e)-(g) are met. Descriptions of how information in this report addresses the acceptance criteria associated with the integrated sub-issue of *Volcanic Disruption of Waste Packages* (NRC 2003 [163274], Section 2.2.1.3.10.3) are provided in Attachment IV.

4.3 CODES AND STANDARDS

No specific formally established codes or standards have been identified as applying to this scientific analysis activity.

5. ASSUMPTIONS

This section identifies assumptions that are used in this analysis. The discussion of each assumption includes four elements: (1) a statement of the assumption; (2) the rationale for the assumption; (3) a statement on the need for further confirmation, if any, of the assumption; and (4) a statement where the assumption is used in the calculation.

5.1 TREATMENT OF WASTE PACKAGES IN DRIFTS INTERSECTED BY A DIKE AND IN DRIFTS NOT INTERSECTED BY A DIKE (Igneous Intrusion Scenario)

Assumption: 1. It is assumed that for any drift intersected by a dike, all of the waste packages located in that drift will fail. In other words, they will provide no further protection for the waste.

2. It is assumed that for any drift not intersected by a dike, none of the waste packages located in that drift will fail.

Rationale: 1. Since the emplacement drifts will not be backfilled, there are no credible mechanisms to block or mitigate the resulting effects from the dike intrusion upon the waste packages.

2. The presence of backfill in ventilation drifts, access drifts, and turnouts will serve as credible mechanisms, provided sufficient engineering is implemented, to protect waste packages in emplacement drifts which are not exposed directly to magma (i.e., drifts which are not intersected by a dike).

Confirmation Status: Two analyses, *Dike/Drift Interactions* (BSC 2004, [167778]) and *Igneous Intrusion Impacts on Waste Packages and Waste Forms* (BSC 2003, [165002]) include evaluation of possible effects on waste packages in drifts which are not directly hit by a dike, but which are adjacent. Such effects include the penetration of magma into backfilled locations (from [167778]), and penetration of corrosive gases into backfilled locations or through pillars to drifts which are not (initially) intersected by a dike, as well as effects of elevated temperatures (from [165002]). For part 1 of this assumption, Section 6.5.1.1 of [165002] concludes that waste packages in drifts which are intersected by dikes will provide no further protection to the waste. For part 2 of this assumption, results of scoping calculations show that the combination of backfill plus an engineered plug/bulkhead/etc can be designed to limit the flow of magma between drifts. These calculations will be included in the next revision of [167778].

Use Within the Analysis: This assumption set is used in Section 6.3.

5.2 CONSTANT CONDUIT DIAMETER PER REALIZATION (Volcanic Eruption Scenario)

Assumption: It is assumed that all conduits have the same diameter, for any particular realization.

Rationale: This is a simplifying assumption. A distribution of conduit diameters is sampled in this analysis. The assumption only refers to the fact that for each realization, the conduit diameter that is sampled from the distribution is held constant. In other words, conduit diameters do vary from one realization to the next, but within any particular realization, the diameter is held constant.

Confirmation Status: No additional work is planned to verify this assumption.

Use within the Analysis: This assumption is used in Section 6.4 to simplify the calculation of the number of waste packages hit by an eruptive conduit.

5.3 WASTE PACKAGES DAMAGED BY A CONDUIT (Volcanic Eruption Scenario)

Assumption: The number of waste packages within an eruptive conduit is assumed to be simply a function of conduit area and the average waste package density within the repository. No attempt is made to specifically determine or assign where in the repository a conduit occurs. So long as the conduit occurs in the repository, the number of waste packages hit is determined by multiplying the conduit area by the calculated 'waste package density' factor, which is the total number of waste packages divided by the total repository area.

Also, although magma associated with an eruption may contact other packages along the drift, the magma moving with sufficient vertical velocity to entrain waste in an eruption is assumed to be located only within the conduit. This relates to the previous paragraph, because if additional waste packages outside of the conduit profile fail, then this simplified calculation approach would not be viable.

Rationale:

The average waste package density is calculated by dividing the total planned number of waste packages by the total planned active repository area, including pillars. That approach is supported in part by the facts that the waste packages are uniformly distributed along each emplacement drift, and those emplacement drifts are evenly spaced within the repository footprint. In other words, the waste packages are relatively evenly spaced in two different directions (therefore anisotropic) throughout the repository. Considered over the scale of the entire repository, this leads to a relatively uniform waste package density, which supports the use of an average value.

The net effect of the assumption is that any conduit that penetrates the repository will damage some number of waste packages to a sufficient degree that they provide no further protection for the waste. If, instead of this approach, the analysis were to explicitly overlay conduit profiles onto the repository and calculate intersections, along the lines of the igneous intrusion scenario (described in detail in Section 6.3), there would be many cases in which conduits never actually intersect with drifts at all. However, it is not possible to assert that this is a conservative assumption, because the reverse is true as well. In other words, for explicit overlay of conduits, there would likely be cases where the conduits would be calculated to intersect more waste packages than in the current analysis. This current approach leads to an answer between these two extremes, and allows for simplification of the analysis.

The second part of the assumption has been termed the ‘cookie cutter’ approach. Conduits are secondary features, spawned by dikes, which in the cases of concern, have already penetrated the repository and filled intersected drifts with magma. This is supported by *Dike/Drift Interactions* (BSC 2004 [167778], section 6.4.4.1). The magma in the drifts would not impact the waste packages sufficiently to cause any additional waste to move into the conduit and be captured by the eruption. Therefore it is assumed there will be no significant interaction of conduit magma with the waste packages outside of the conduit boundary.

Confirmation Status: No additional work is planned to verify this assumption.

Use within the Analysis: This assumption is used in Section 6.4 for the calculation of the number of waste packages hit by an eruptive conduit.

5.4 DIKES IN A SWARM OCCUR IN PARALLEL

Assumption: It is assumed that for any scenario cases in which more than one dike is sampled, all dikes are parallel to each other. The sampled azimuth value therefore applies to all dikes in the swarm.

Rationale:

This is the general case in nature. Vertical tabular dikes propagate in a direction perpendicular to the direction of minimum compressive stress in the host rock formation, as discussed in Pollard, 1973 ([166923] p. 254).

Confirmation Status: No additional work is planned to verify this assumption.

Use within the Analysis: This assumption is used in Section 6.3 as part of the geometric simulation of dike swarms.

6. SCIENTIFIC ANALYSIS DISCUSSION

6.1 ANALYSIS OBJECTIVES

The objectives of these analyses are to develop predictive distributions for the number of waste packages hit (damaged) via igneous intrusions (dikes) or eruptive events (conduits). These distributions, provided as CDFs, will be inputs to the source term determination for the Igneous Intrusion scenario and for the Volcanic Eruption scenario in the TSPA-LA.

6.2 FEATURES, EVENTS, AND PROCESSES INCLUDED IN THE ANALYSIS

The development of a comprehensive list of features, events, and processes (FEPs) potentially relevant to post-closure performance of the potential Yucca Mountain repository is an iterative process based on site-specific information, design, and regulations. The approach for developing the list of FEPs in support of the *Total System Performance Assessment* for the Site Recommendation (TSPA-SR) (CRWMS M&O 2000 [153246]) was documented in Freeze et al. (2001 [154365]). The initial FEPs list contained 328 FEPs, of which 176 were included in TSPA-SR models (CRWMS M&O 2000, Tables B-9 through B-17 [153246]). To support the TSPA-LA, the FEPs list was re-evaluated in accordance with the *Enhanced Plan for Features, Events, and Processes (FEPs) at Yucca Mountain* (BSC 2002, Section 3.2 [158966]).

Tables 6 and 7 of the TWP for igneous activity analysis (BSC 2003 [166289]) provide a listing of both included and excluded FEPs for each of the disruptive events (DE) analysis and model reports. One FEP that was listed as included in the TWP, 1.2.04.01.00 Igneous Activity, was deleted during the FEPs review for TSPA-LA that was conducted as part of the Enhanced FEPs Plan. The FEP was found to be redundant with more specific igneous related FEPs. The FEP 1.2.04.05.0A Magma or Pyroclastic Base Surge Transports Waste was previously, and continues to be, excluded. The technical basis for exclusion of this FEP was previously provided in (BSC (Bechtel SAIC Company) 2003[163771] Section 6.2.2.4). Although this analysis report may provide information cited in the technical basis for exclusion, the following discussion addresses only implementation (either implicit or explicit) within the TSPA-LA model, consistent with guidance provided in Appendix A of the *Scientific Processes and Guidelines Manual* (BSC 2002 [160313]).

Table 3 provides a list of FEPs that are included in the TSPA-LA through the use of the results of the calculation described in this document. For each of the included FEPs listed in Table 3, the implementation in TSPA-LA is described in this report. Details of the implementation are summarized in the table, including specific reference to sections within this document. The parameters that address the included FEPs are also listed. The sources of input for these parameters are described in Section 4 for input parameters and elsewhere in Section 6 if they were specifically developed within this document.

Formation of a new volcano is accompanied by one or more dikes in the subsurface and some combination of scoria cone, spatter cones, ash and lapilli fall, and lava flows on the surface (BSC 2003 Section 5.0 [166407]). The TSPA-LA treats an intrusive and an extrusive event simultaneously, albeit computationally separated. In the extrusive event, magma enters the repository drifts, and magma and ash, potentially with entrained waste, are released to the surface via an eruptive conduit. This is termed the Volcanic Eruption Scenario in this report, and is the subject of Section 6.4. In the intrusive event, waste packages are damaged by the dike intrusions but eruptive conduits do not form, and radionuclides are released from the cooled intrusion to the subsurface by groundwater flow and transport processes. This is termed the Igneous Intrusion Scenario in this report, and is the subject of Section 6.3. The parameters and distributions developed in this analysis report are used directly in the TSPA-LA. The FEPs listed in Table 3 are part of the conceptual basis for such a scenario.

Table 3. Included FEPs for this Scientific Analysis Report and their Disposition in TSPA-LA

TSPA-SR FEP Number, Name, and Description	TSPA-LA FEP Number, Name and Description	Section Where Disposition is Described	Summary of TSPA-LA Disposition
1.2.04.04.00 Magma Interacts with Waste *An igneous intrusion in the form of a dike occurs through the repository, intersecting waste. This leads to accelerated waste container failure (e.g., attack by magmatic volatiles, damage by fragmented magma, thermal effects) and dissolution of waste (Commercial Spent Nuclear Fuel (CSNF), Defense Spent Nuclear Fuel (DSNF), and U.S. Department of Energy (DOE) High Level Waste (DHLW)*	1.2.04.04.0A Igneous Intrusion Interacts with EBS Components *An igneous intrusion in the form of a dike occurs through the repository, intersecting the repository drifts. Magma, pyroclastics, and volcanic gases enter the drift and interact with the EBS components including the drip shields, the waste packages pallet, and the invert. This leads to accelerated drip shield and waste package failure (e.g. attack by magmatic volatiles, damage by flowing or fragmented magma, thermal effects) and dissolution or volatilization of waste.*	Sec. 4, 6.3, 6.5, and 7	The analysis uses the outputs from the revisions of the analysis reports *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [163769]), *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2003 [166407]); and *Dike/Drift Interactions* (BSC 2004 [167778]) along with repository design information to calculate the number of waste packages exposed to defined magmatic-related environments, which is the primary focus of this FEP. The analysis uses spreadsheet calculation operations and a custom software program to evaluate geometric relationships between dike intersection area and conduit geometry and the number of waste packages impacted by dikes. The types of information used can include, but may not be limited to: • Repository design information (repository area, drift diameter, drift spacing, waste package length, and waste package spacing). • Igneous event probability. • Probability distributions and parameters associated with dikes within the repository (dike length, dike azimuth angle, dike thickness, and number of dikes in a swarm). The parameters developed in this document related to this FEP include: • Probabilities for dike swarm configurations The results of the number of waste packages hit by an igneous intrusion analysis include CDFs for the number of waste packages hit in an igneous intrusion scenario and in an eruptive release scenario. Outputs developed in this document related to this FEP: • CDFs for the number of waste packages damaged by dike swarms These CDFs are used directly and explicitly in the TSPA-LA model to determine the source term for the Igneous Intrusion Scenario. Because the CDFs are dependent on the underlying inputs, the underlying inputs and related FEPs are considered to be implicitly included in the TSPA-LA model.

Table 3 Continued. Included FEPs for this Scientific Analysis Report and their Disposition in TSPA-LA

TSPA-SR FEP Number, Name, and Description	TSPA-LA FEP Number, Name and Description	Section Where Disposition is Described	Summary of TSPA-LA Disposition
1.2.04.06.00 Basaltic Cinder Cone Erupts through the Repository *As a result of an igneous intrusion, a cinder cone forms at land surface. The conduit(s) supplying the vent(s) of the cone pass(es) through the repository, interacting with and entraining waste.*	1.2.04.06.0A Eruptive Conduit to Surface Intersects Repository *As a result of an igneous intrusion, one or more volcanic vents forms at land surface. The conduit(s) supplying the vent(s) pass(es) through the repository, interacting with and entraining waste*	Sections 4, 6.4 and 7	The analysis uses the outputs from the revisions of the analysis reports Characterize Framework for Igneous Activity at Yucca Mountain, Nevada (BSC 2003 [163769]), Characterize Eruptive Processes at Yucca Mountain, Nevada (BSC 2003 [166407]); and Dike/Drift Interactions (BSC 2004 [167778]) along with repository design information to calculate the number of waste packages exposed to defined magmatic-related environments. The analysis uses spreadsheet calculation operations to evaluate geometric relationships between conduit geometry and the number of waste packages impacted by conduits. The types of information used include, but may not be limited to: • Repository design information (repository area, drift diameter, drift spacing, waste package length, and waste package spacing). • Igneous event probability. • Probabilities and parameters associated with conduits occurring within the repository (conditional probability that more than one conduit will occur within the repository footprint and conduit diameter distribution). Parameters related to this FEP and developed in this analysis include: • Composite joint probability distribution for number of eruptive centers (conduits) in a repository • Eruptive conduit diameter For the volcanic eruption scenario, the analysis in this report determines the number of waste packages directly intersected by conduits. Outputs related to this FEP and developed in this document include : • A CDF for the number of waste packages contained in an eruptive conduit as a function of a distribution of possible conduit diameters. This output was used directly in the TSPA-SR model to determine the source term for the Volcanic Eruption Scenario. It is included as an option for the same purpose. • A CDF for the number of waste packages damaged by one or more eruptive conduits. This CDF incorporates the previous CDF as well, integrating that with a distribution for the number of conduits that could penetrate the repository. It is designed to be used directly in the TSPA-LA model.

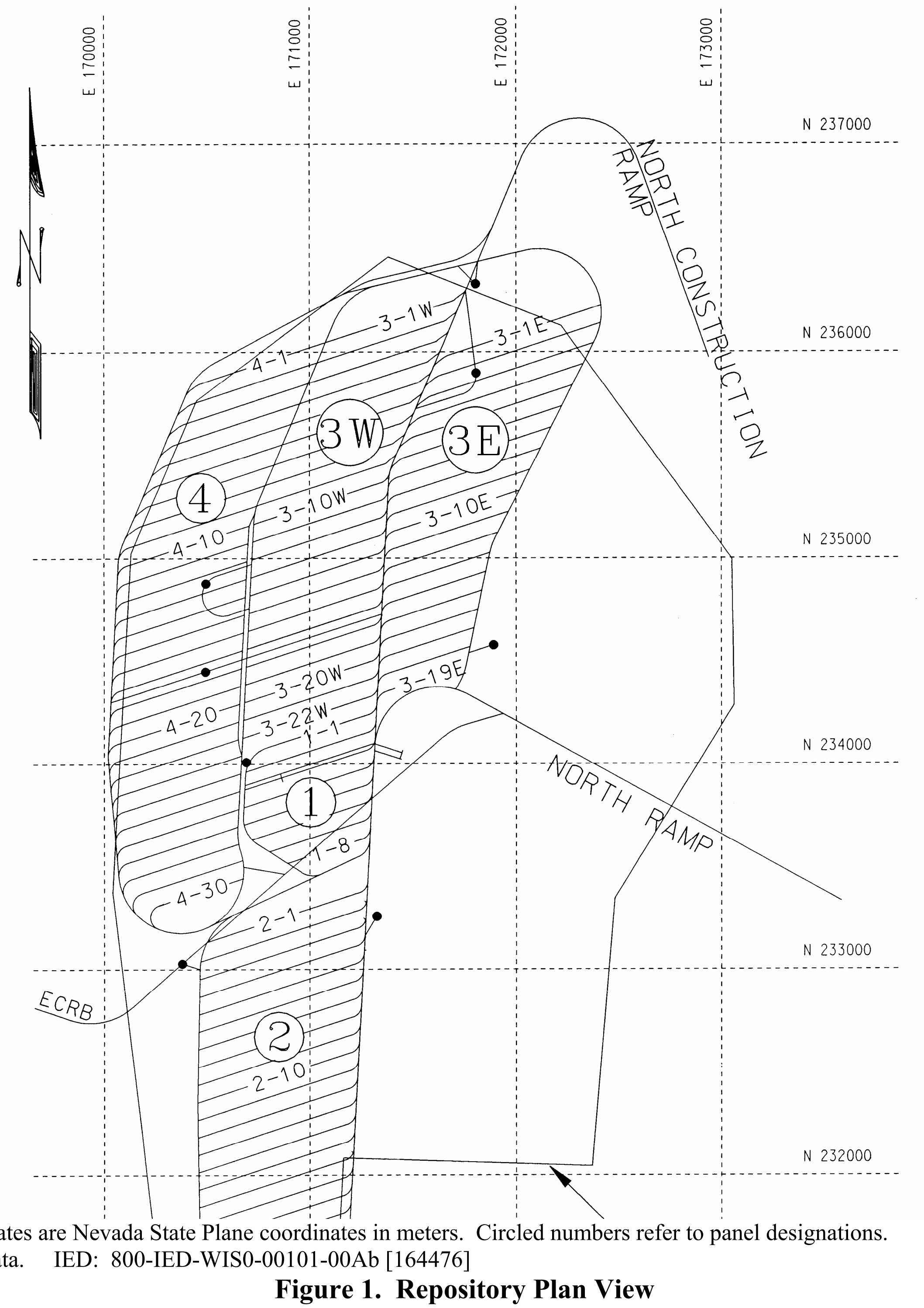
6.3 NUMBER OF WASTE PACKAGES HIT BY IGNEOUS INTRUSION (Igneous Intrusion Scenario)

6.3.1 Problem Definition

As stated in Section 1, the Igneous Intrusion Groundwater Release scenario ("igneous intrusion" scenario, for short) considers the number of waste packages damaged if they were to be encapsulated by magma as a result of an igneous intrusion. The variables that affect this consideration include geologic and geometric elements. The geologic elements are largely stochastic parameters. The geometric elements concern both geologic features and the current repository design. A listing of these elements, their values, and their qualified sources are tabulated and described in Section 4. In addition, the assumptions that bear on this analysis are described in Section 5.

The primary geologic elements considered are associated with volcanic dikes themselves. As described in *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC, 2003) [163769], dikes are vertically oriented, relatively thin tabular bodies of magma and entrained volatiles, which have a remote but finite possibility to rapidly rise from the deep subsurface and intersect the repository in a wide variety of geometric configurations. Among other attributes, these dikes have the potential to be oriented in almost any azimuth angle (horizontal angle starting from 0 degrees at due north and increasing in a clockwise direction). They can also vary widely with regard to the length through the repository that they intersect. Moreover, such dikes can occur in swarms in which the spacing between parallel dikes may vary. Note that the assumption in Section 5.4 covers the case for parallel dikes. Geometric features of each simulated dike set are included in Attachment I, file "dikedata.txt" and are described in more detail subsequently.

The primary geometric elements include the features of dikes just described, as well as the layout of the repository. The repository design used in this analysis is depicted in Figure 1. The figure shows four major panel areas, numbered 1, 2, 3 (W and E), and 4, covering a total area of 5,419,074 square meters, and consisting of 96 individual drifts (800-IED-WIS0-00103-000-00Ab, Figure 2 and Table 8, [164491]). The coordinate information shown on the figure is in feet. In addition to the extensive pillars between each drift, there are access and ventilation drifts, which are generally oriented north/south. There is also a north-south oriented rock wall, which separates panel 4 from panel 1 and the southern half of panel 3W. This analysis utilizes the current information that access drifts, ventilation drifts, and turnouts will be backfilled, and those backfilled portions will serve as effective barriers to lava flow (but not to dike propagation), as described in Assumption 5.1. The main section of each drift, which contains the waste packages, will not be backfilled. Therefore, it is assumed (see Assumption 5.1) that for any drift intersected by a dike, all waste packages therein will fail. The essential repository geometric features to capture for this analysis are the repository perimeter and drift coordinate information. The center endpoint coordinates for each drift are included in Attachment I, worksheet "original" of spreadsheet "RepGeometry.xls". The approximate perimeter coordinates for the entire repository are included in worksheet "perimeter" of the same spreadsheet.



Coordinates are Nevada State Plane coordinates in meters. Circled numbers refer to panel designations.
Input Data. IED: 800-IED-WIS0-00101-00Ab [164476]

Figure 1. Repository Plan View

The southern half of panel 2, below drift # 2-17 (which is the seventh drift below the drift labeled '2-10' in the figure), is a contingency area. This contingency area is considered in the design, but not in the calculations of this report. The analyses in this report are entirely conditional upon the current design of Figure 1. Any changes to the drift layout may lead to a need for a change in the analyses of this report. The design reflects a concentrated arrangement of waste packages, which leads to elevated temperatures in the drifts.

Waste package "spacing" refers to the combined length of one waste package and the distance to the next adjacent package within a drift. The value of average waste package spacing must be determined in order to correlate each drift with an anticipated number of waste packages. The value is developed towards the bottom of worksheet "original" of the spreadsheet "RepGeometry.xls" of Attachment I. The total length of emplacement drift in the repository is simply divided by the total number of waste packages. After rounding, the number is 5.2 m per waste package.

The calculation approach consists of a general treatment following these steps:

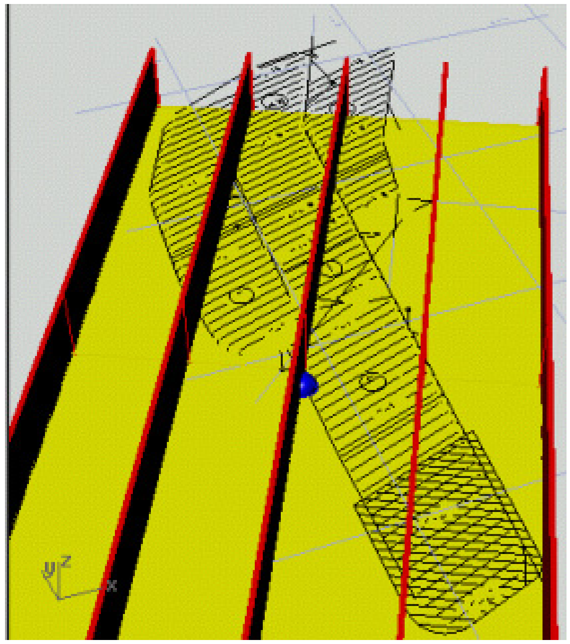
A. Develop with the assistance of Latin hypercube sampling, a series of realizations of plausible dike swarm configurations which could intersect the repository. Each realization must honor all input constraints and rules.
B. Overlay the dike swarm configurations onto the repository layout geometry and tally the number of drifts intersected for each realization.
C. Given an average working value for the spacing of waste packages, determine the total number of waste packages hit for each realization.
D. Develop a set of cumulative distribution (CDF) functions for the numbers of waste packages hit for each series of realizations.
E. Produce an average CDF from the set in the previous step.

6.3.2 Calculation Step A.

Dikes are elongate vertically oriented tabular bodies of magma, which can extend laterally for kilometers from an underlying melt zone within the mantle. More than one dike can result from the same mantle melt zone and multiple dikes generally form in parallel. Their azimuth angles can vary according to a distribution. A grouping of more than one dike related to the same magmatic event is called a swarm. If such dikes were formed below the repository, and they reached the near-surface environment, a number of drifts in the repository could be intersected and a number of its waste packages would fail. Figure 2 is an illustration of a hypothetical swarm of dikes, depicted as red vertical slabs, intersecting the repository. The blue hemisphere represents an 'anchor point', which is described subsequently.

The extent of damage would be a function of some constant values and many variables, including the length of the dikes in the swarm, the number of dikes in the swarm, the spacings between each dike, the angles at which the dikes intersect the repository, the maximum thickness of dikes, and the dike entry locations along the repository perimeter. This analysis takes all of these factors into account through multiple parameter distribution sampling. It depends heavily on the probabilistic treatments of many of these variables contained in two analysis reports; *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* analysis report (BSC

2003 [163769]) and *Characterize Eruptive Processes at Yucca Mountain, Nevada* analysis report (BSC 2003 [166407]).



For illustration purposes only.

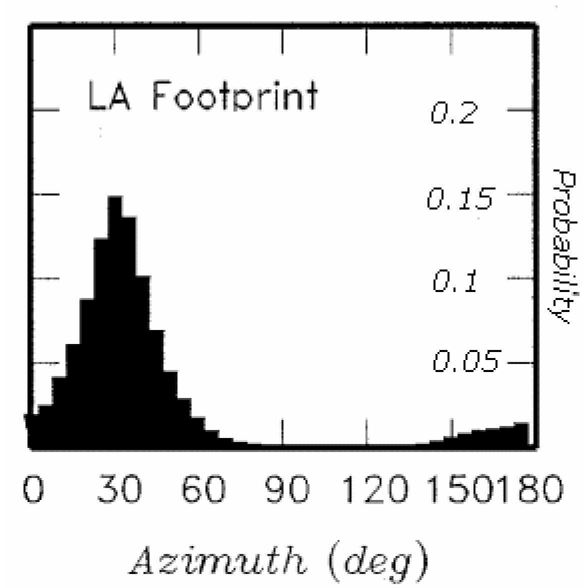
Figure 2. Conceptualization of a swarm of dikes penetrating the repository footprint

The first calculation step is facilitated primarily through the use of the code LHS (Version 2.51, STN 10205-2.51-00 [167794]) in accordance with the rules for dike configuration. LHS is a FORTRAN code which provides simultaneous binning of multiple parameter distributions for use by subsequent models or calculations. Through LHS, one can generate correlated or uncorrelated parameter sets which are representative of distributions generated by more resource- and time- expensive methods, such as the Monte Carlo method.

An input file was prepared for LHS (Attachment I) which contains the following distribution parameter sets:

1. Dike length within repository. Source is described in Row 3 of Table 1, this report. Sampled dike lengths can range from near zero m to over 5,000 m. The sampled value represents the length of the anchor extension line. This variable is defined in more detail subsequently.
2. Dike azimuth angle. Source is described in Row 3 of Table 1, this report. The related analysis package *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada.* BSC 2003 [163769], contains a figure set (Figure 22) representing various distributions of possible azimuth angles through the repository that is illustrative of the distribution used. Azimuth angles are measured in degrees, going clockwise, from due north. Examination of the graph, which plots mean azimuth angles, reproduced here as Figure 3, shows a relatively narrow distribution, clustered around the modal value of 30 degrees. The sampled angle initially represents the azimuth angle of the anchor extension line, initially, and then it is replicated for the swarm dikes.

3. Number of dikes. Source is described in Row 11 of Table 1. This is a truncated log-normal distribution with a minimum value of 1 and a modal value of 3. The 95th percentile is set at 6. Given the LHS setting to produce 1000 realizations, this leads to a small population of cases where the number of dikes can run from 7 to roughly15.
4. Spacings between dikes. Source is described in Row 13 of Table 1. This is a random uniform distribution, with a minimum value of 100 m and a maximum possible spacing of 690. The spacing values are calculated independently for each pairing of adjacent dikes. In other words, for any given realization, there can be many unique inter-dike spacing values. The total width of the swarm will be the sum of the dike spacings. The first dike will fall at a point that is a distance of half of the swarm width to the 'left' side of the anchor extension line (if viewing the line with the anchor point at the bottom; see next item).
5. Central dike swarm entry location (also called "anchor point" and defined in more detail subsequently). An anchor point is assigned to a random location along the repository perimeter for each realization. The variable position of entry locations is assigned a uniform distribution.



Data Source: Figure 22 of (BSC 2003, [163769]). Data in DTN # LA0303BY831811.001 [163985]

Figure 3. Mean Hazard, Azimuth Angle Distribution for Repository Intersection.

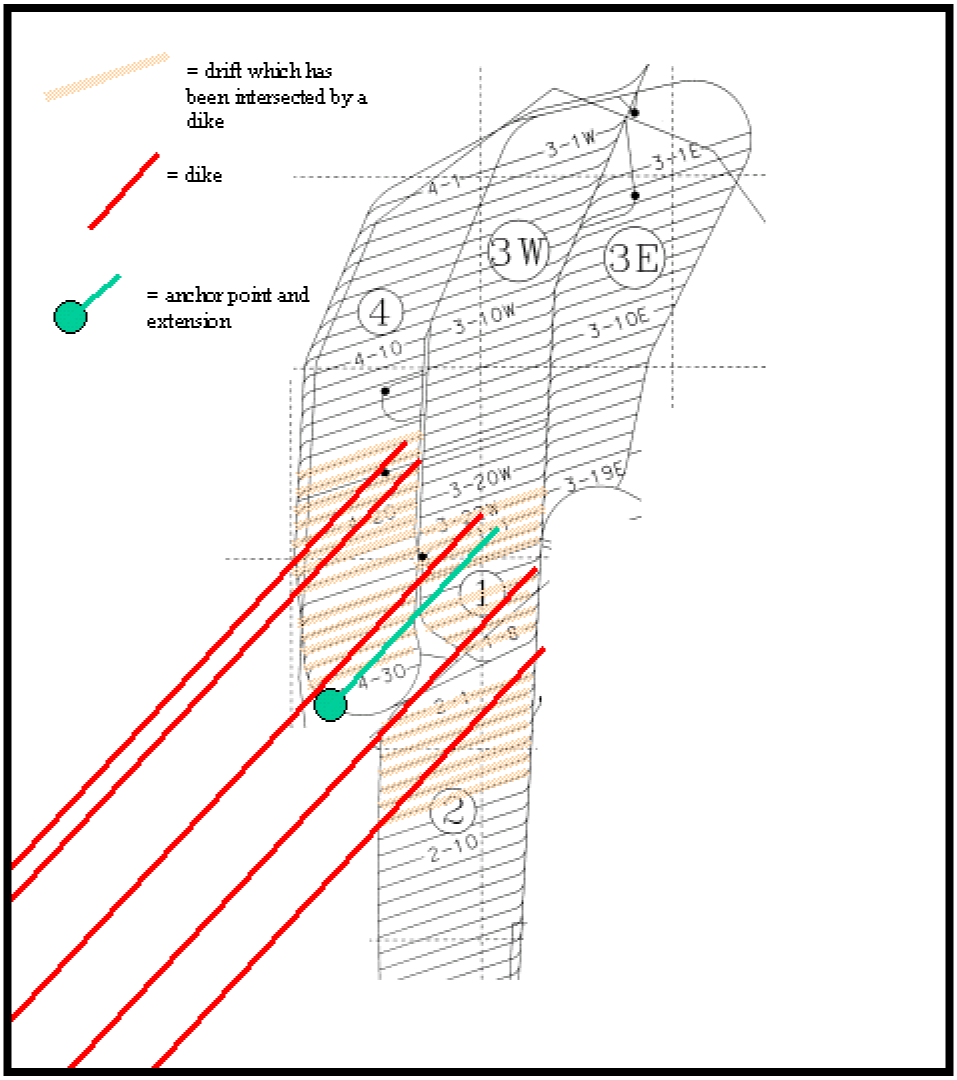
Parameters which are not treated as uncertain variables include dike thickness and repository layout and dimensions. The repository is treated as a configuration which does not change. Dike thicknesses do vary, but the maximum expected thickness of 4.5 m (DTN#: LA0311DK831811.001 [166301]) at Yucca Mountain is still small compared to the 81 m spacing between repository emplacement drifts (800-IED-MGR0-00201-000-00a BSC 2004 [167040]). A maximum dike thickness is "hard-coded" into DIRECT via bounding box algorithms, with additional thickness above and beyond the maximum value of 4.5 m. This adds an element of conservatism, and is treated in more detail subsequently.

Figures 4 and 5 illustrate the basic conceptual rules, and the type and variety of outcomes that can be realized. After conducting an LHS run with the proper sampling and distribution criteria, a set of 1000 parameter combination realizations is produced. This set is captured in the file LHS.dat, which is input to the DIRECT code. The DIRECT code, using the anchor point and anchor extension line as preliminary building blocks, builds a geometric representation of each realization and explicitly computes the intersections between each dike and drift. Since three replicates were conducted, there are actually three lhs.dat type files included. The three basic files are lhs_1.dat, lhs_2.dat, and lhs_3.dat. For each run of DIRECT, one of these files is renamed as lhs.dat.

In the example realization shown in Figure 4, five dikes (red lines) having a northeast bearing intersect the repository and a number of internal waste emplacement drifts. The orange semi-transparent zones identify repository drifts which have been intersected by these dikes. The green dot represents the sampled anchor entry point. The anchor entry point can occur anywhere along the repository perimeter, according to a sampled value. The green anchor extension line represents both the sampled azimuth angle and the sampled dike length (the dike portion penetrating the repository only).

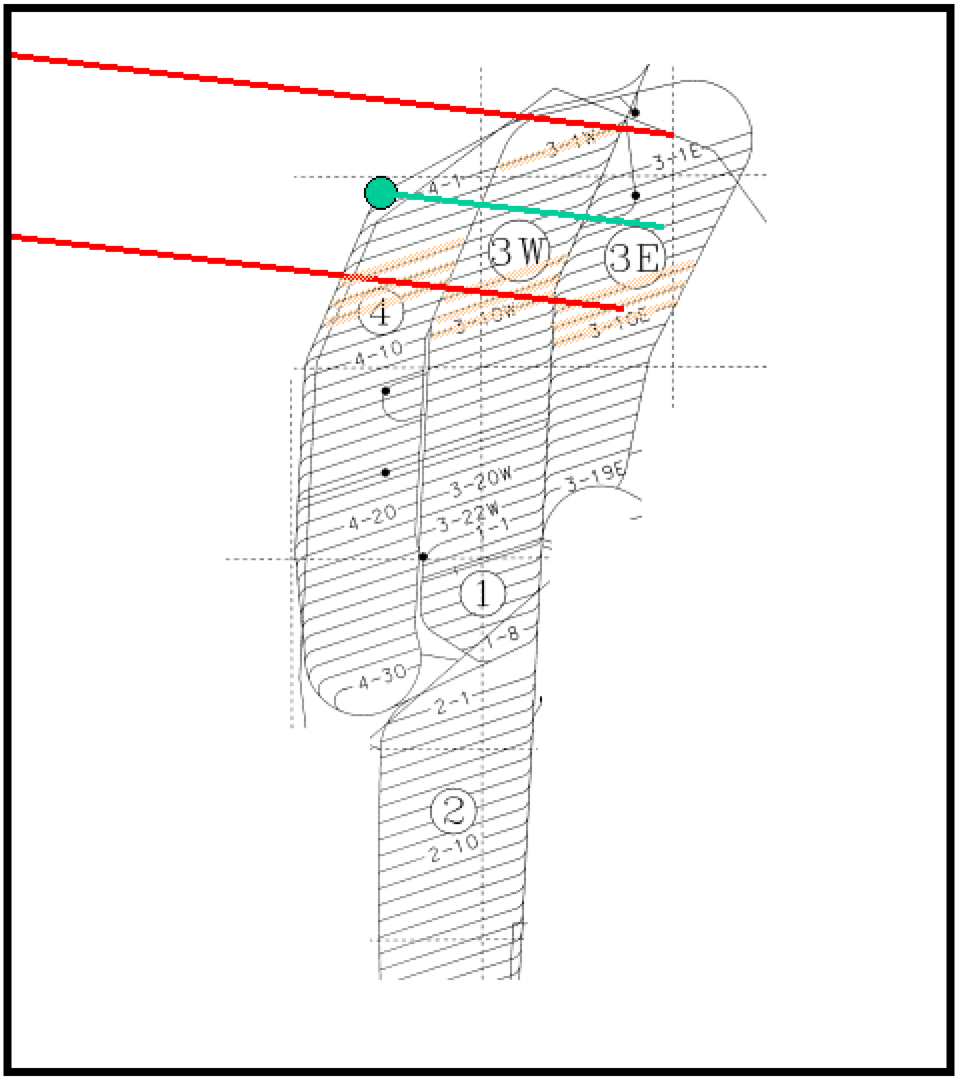
All dikes are parallel to the anchor extension line, but have variable spacing (also via sampling) between them. The anchor point does not correspond to any particular dike. Rather, the anchor point and extension are positioned at the middle of the entire dike swarm.

Figure 5 shows an alternate sampled realization. In this case, there are only two dikes, which now have an easterly bearing and which enter the repository from a more northerly position than the previous figure. The anchor point and extension are, as always, midway between the extent of the dike swarm. Clearly the variations in dike swarm configuration can and will lead to significant differences in the calculated number of drifts intersected.



For illustration purposes only.

Figure 4. Example of a dike swarm configuration

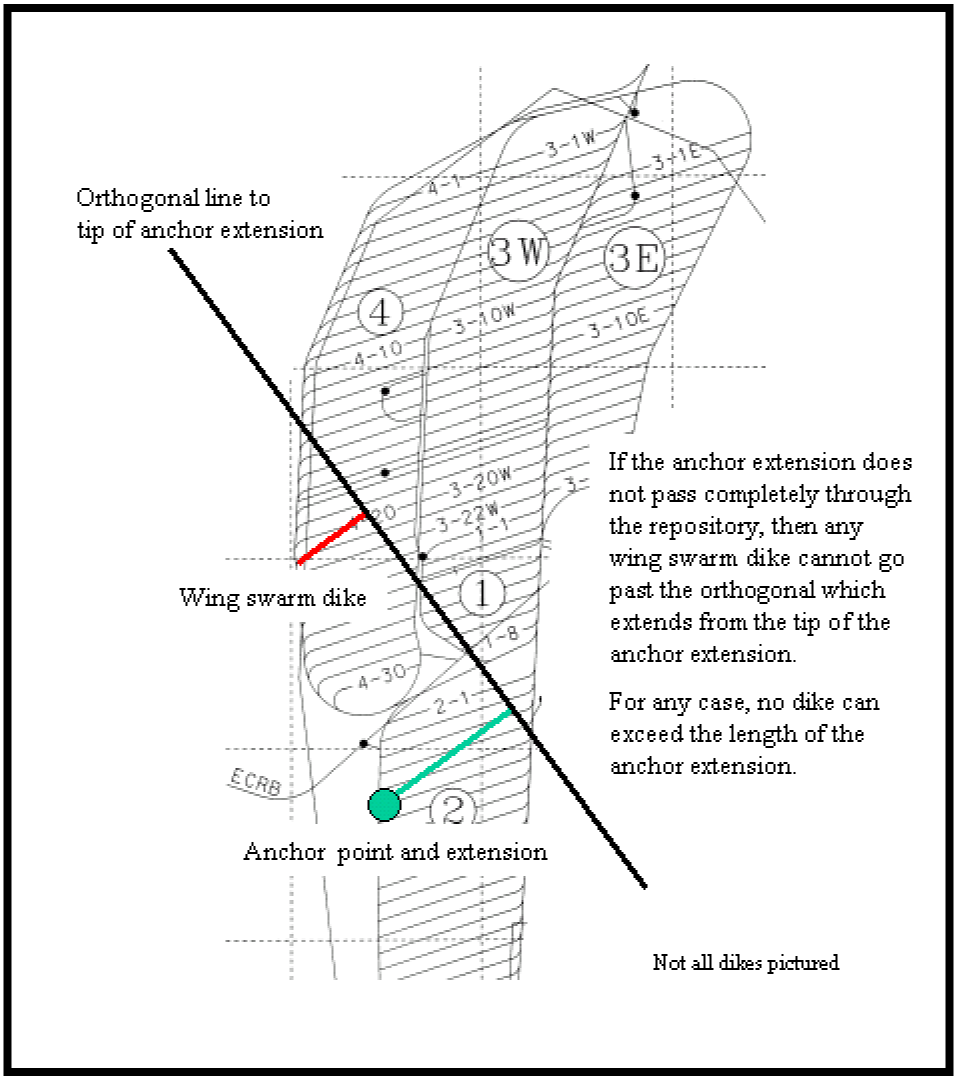


For illustration purposes only.

Figure 5. Second example of a dike swarm configuration.

These represent only two of many possible configurations. The nature and extent of possibilities are controlled by features, which fall into two distinct categories. One category represents the sampled (and generated) distributions described earlier. The other category represents rules used to control specific aspects of the swarm dikes.

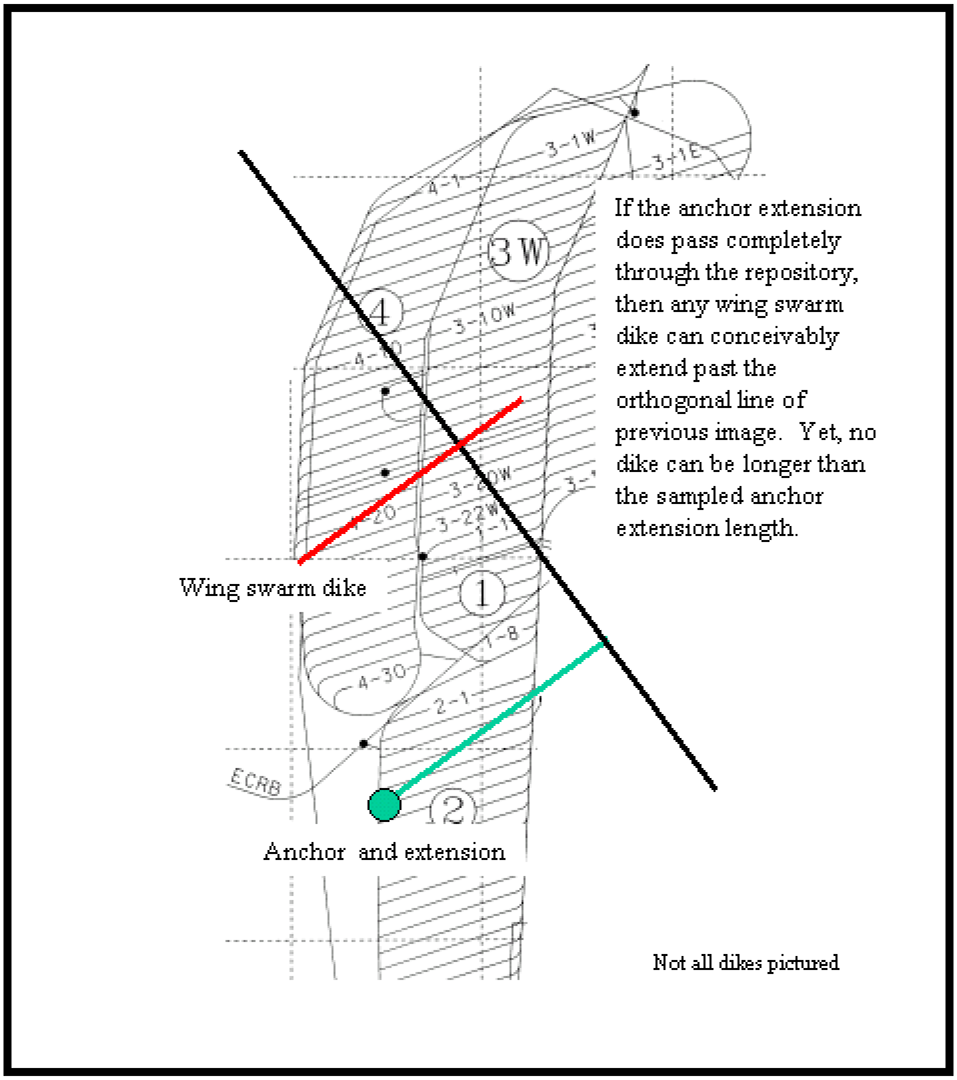
The rules primarily involve the lengths and spacings of dikes, as determined by their geometric relationships to the anchor extension. Figures 6 and 7 illustrate the most important of these length rules. Note that non-pertinent features, such as the portions of dikes outside the repository are left out in these figures. In Figure 6, a red dike is shown to the northwest of the anchor extension. That dike is shorter than the anchor extension because of the first rule. This rule dictates that, for cases in which the anchor extension does not project all of the way through the repository, no dike can extend beyond a line that is adjacent and orthogonal to the tip of the extension line. This rule generally honors the fact that the sampled dike length represents the intended maximum repository intersection length of dikes for that realization.



For illustration purposes only

Figure 6. Illustration of dike configuration rule #1.

The second rule covers dike configurations for cases in which the anchor extension does project all of the way through the repository. This is illustrated in Figure 7. The figure indicates that for this case, all dikes that penetrate the repository will be no longer than the length of the sampled anchor extension. Such dikes can be lower in length, due to possible cut-offs, depending upon their origination point. In fact, for both rules an added requirement is that no dike exceeds the length of the anchor extension. Once again, this honors the fact that the sampled dike length (represented by the dike emission line) represents the intended maximum repository intersection length of dikes for that realization.



For illustration purposes only

Figure 7. Illustration of dike configuration rule #2.

A third rule, not illustrated, concerns the entry point, or lack thereof, for all dikes. From the anchor point itself, another orthogonal line, parallel to the orthogonal line just described, extends in both directions. The sampled dike spacings are initially registered to this line. For each dike spacing, a dike extension line is then projected in the same direction as the anchor point extension line. If the dike extension line intersects the repository perimeter, then the dike is drawn into the repository according to the previous rules. If the dike extension line does not penetrate the repository perimeter, then, although the dike is registered, no further attempt is made to force the dike to penetrate the repository.

A fourth rule, also not illustrated, concerns a possible reversal in the sampled anchor extension angle. Consider the case where a sampled anchor point position places it at the east end of the repository, and the sampled anchor extension azimuth angle points to the east. This would ensure that most, if not all dikes never intersect a single drift. The rule simply causes the azimuth angle to be reversed under those circumstances.

6.3.3 Calculation Step B.

This step involves overlaying the dike swarm configurations onto the repository layout geometry and tallying the number of drifts intersected for each realization. This procedure involves several sub-steps. Both the repository layout geometry and the sampled dike geometry must be realized within the DIRECT code for intersections to be calculated automatically. Therefore the first sub-steps are the determination of these geometries and the exporting of the same into the DIRECT environment.

DIRECT is based on the underlying Torque Game Engine (www.garagegames.com), which, with few exceptions, requires that geometric objects be initially imported into the system as binary objects called shape files, having a '.dts' extension. Moreover, the DIRECT geometric coordinate space has a different scale and orientation than the Nevada State Plane Coordinates space used to define the repository layout. Therefore geometric transformations must be employed. Note however that as shown subsequently, the final graphics of DIRECT results are easily measured and comparable against input values and original drawings.

DIRECT expects every object to be defined by its initial shape file definition, the midpoint coordinates of the shapefile object, the scaling in the x, y, and/or z axis of the shapefile object, and the rotations of the shapefile object around the x, y, and/or z axes, centered at its midpoint. For drifts, this is set up in worksheet "RepGeometry.xls" (Attachment I) and realized in the DIRECT input file "driftData.txt" (Attachment I). For dikes, this is set up in the output file from the LHS run, which is fed to DIRECT, which produces a separate input file "dikeData.txt" (Attachment I).

Production of shapefiles is a multi-step process:

- In the 3D CAD program Rhinoceros or an alternate CAD program, construct a 'unit prism' for initial drift geometry.
- Export it as an AliasWavefront '.obj' file (this is simply a format that both Rhinoceros can write and that MilkShape can read)
- Import that file into MilkShape. (note that Milkshape has its own drawing capability, but doesn't offer the degree of precision control that Rhinoceros does.)
- Export the file from MilkShape into the 'dts' format (boundingtest1.dts), also known as a shapefile. The object's initial orientation and dimensions are such that it has a unit length in the 'y' axis direction.
- Place the shapefile object into the appropriate directory (example\data\shapes\organic)

Repeat above process to produce a 'unit prism' for all sampled dikes. (boundingtest1.dts, into same directory as above)

The development of the transformation parameters that are applied to the drift shapefile is another multi-step process:

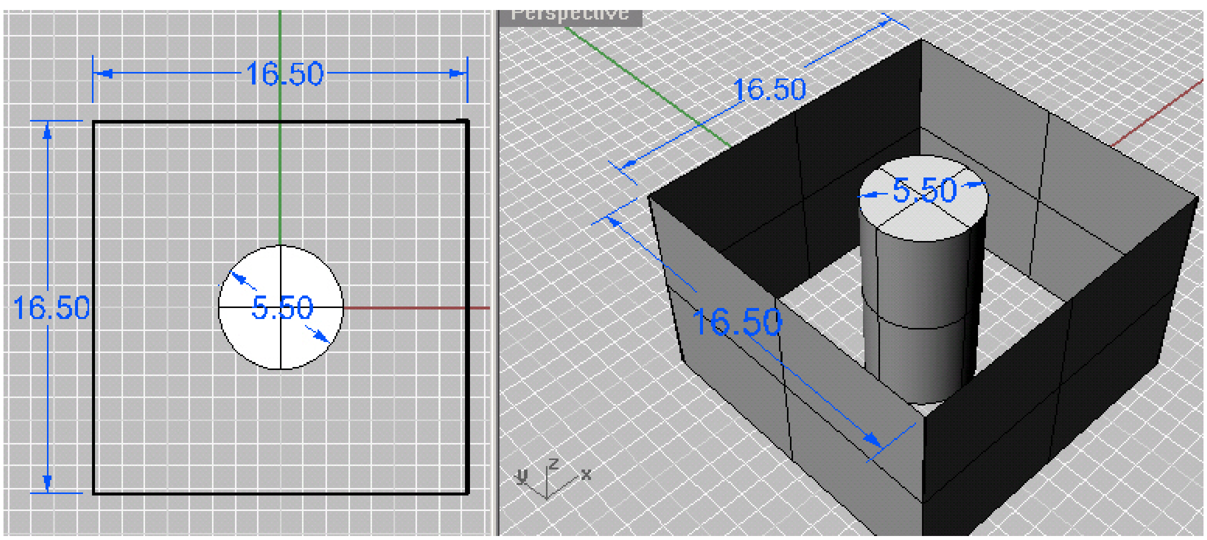
- Start with original IED-supplied drift coordinates (worksheet "original" of spreadsheet "RepGeometry.xls", Attachment I).
- Transform scale and position (by first dividing both coordinates by 100, then subtracting 1710 from the x coordinate, and 2320 from the y coordinate) and confirm the 72 degree

azimuth angle (worksheet “scaled down” of spreadsheet “RepGeometry.xls”) (Attachment I).

- Produce a transformation instruction file (driftData.txt) for input to DIRECT. (worksheet DriftExport” of the spreadsheet “RepGeometry.xls”) (Attachment I).

For all dike sets, DIRECT automatically produces the appropriate transformation parameters and the transformation instruction file, based on the file from the LHS step.

DIRECT has internal coding which takes the .dts files and the transformation instruction files to build the dike-drift geometry for each realization. The resulting dikes and drifts have the proper lengths at this point, and their cross-sectional thicknesses initially retain the 5.5 m dimensions (the dike thicknesses are set to 5.5 m for simplicity, although the sampled 95th percentile dike thickness is only 4.5 m). These cross sectional thicknesses are expanded later within DIRECT in order to produce ‘bounding boxes’ for collision intersection calculations, as illustrated in Figure 7. DIRECT assigns bounding box thicknesses of 16.5 m for both drifts and dikes. This is three times greater than the planned emplacement drift widths of 5.5 m. This is also more than three times greater than the anticipated maximum dike thicknesses of 4.5 m. This treatment adds a conservative bias to the calculation that leads to the counting of more dike and drift intersections than if the actual dimensions were used.



For illustration purposes only. Dimensions shown in meters. Outer box represents bounding box. Cylinder represents a drift, in this case.

Figure 8. Illustration of bounding box setup.

6.3.4 Remaining Calculation Steps (C, D, and E).

The remaining calculation steps are described together in this section.

The collision detection is done in DIRECT by a series of internal algorithms which test for line intersections. For each realization, each line of each bounding box of each dike is tested for intersection against each line of each bounding box of each emplacement drift. Results for each intersected drift are multiplied by the associated number of waste packages per that drift. That number is calculated by dividing the drift length by the average waste package spacing length of 5.2 m. The calculation of this value is documented in column F of the worksheet “original” of the spreadsheet “RepGeometry.xls” (Attachment I). Once DIRECT has tallied the total number of waste packages hit for a realization, the result is written to a separate row in the output file “results.txt”. There is one row per realization, leading to 1,000 rows of data.

DIRECT has automatic and custom viewing features. In automatic mode, DIRECT produces a single file containing all results, but no figures for verification assistance. To set the runs for automatic mode, the user currently must enter, on an MS-DOS window which is set to the same directory as the DIRECT executable, the command line: “direct.exe -dedicated”.

In custom mode, which is the default setup, the user can examine one case at a time. When the code is launched, the first set is shown on the screen. The user can advance one set at a time by pressing the right arrow key. The user can go backward one step at a time by pressing the left arrow key. The user can skip to any of the steps (out of 1,000) by pressing the ‘cntrl’ + ‘j’ keys simultaneously and entering the desired step number.

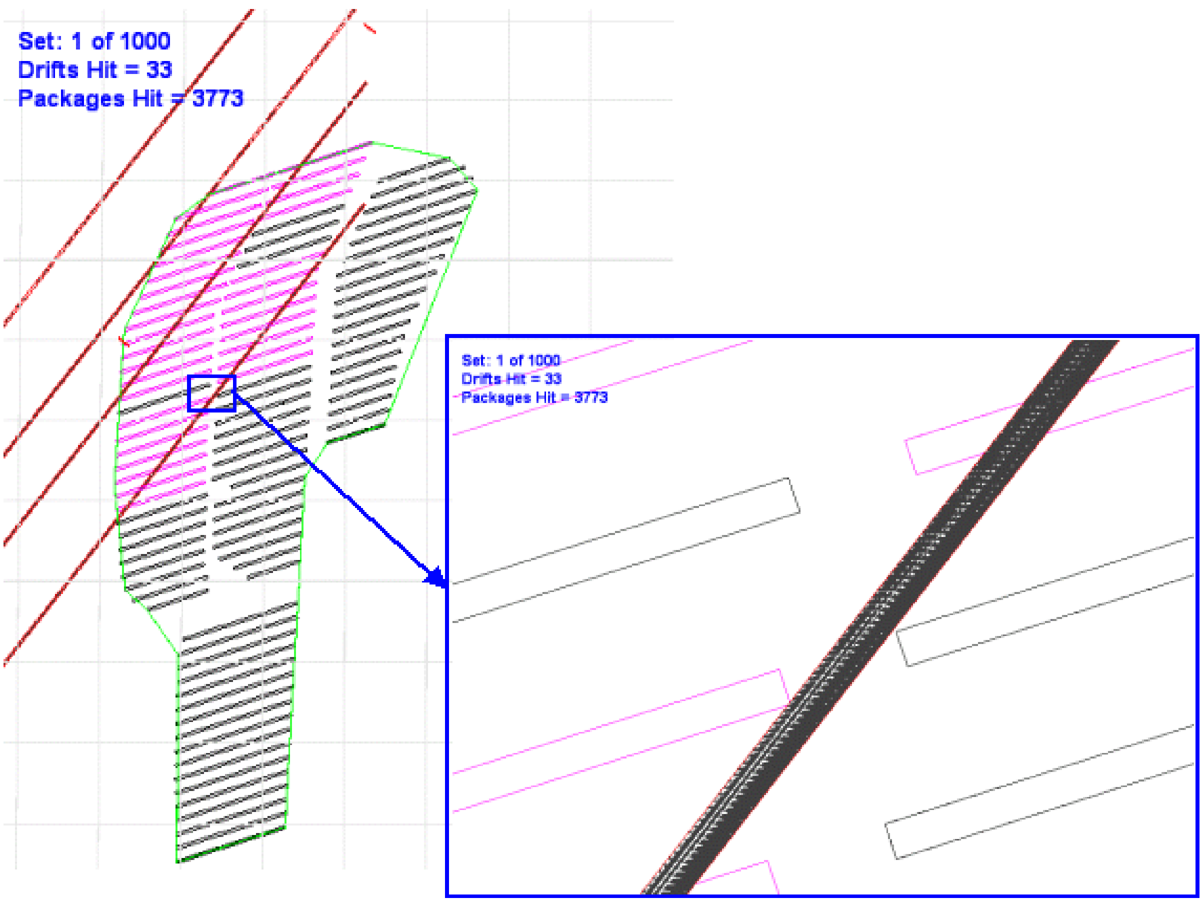
The graphic from that case can then be saved as a .png file for storage and/or printing out. This is done by pressing simultaneously the ‘cntrl’ and ‘p’ keys. Each time these are pressed, an image file in .png format is created in the ‘examples’ directory. Within DIRECT, the image can be zoomed in or out by pressing the ‘w’ and ‘s’ keys respectively. The image can be panned right or left by pressing the ‘d’ and ‘a’ keys respectively. The image can be panned up or down by pressing the ‘o’ and ‘l’ keys respectively. The user can set DIRECT to automatically produce a sequential series of step plots for the current view by pressing the space bar. Pressing the space bar again will toggle out of that mode.

Sample Graphic Results

The Figures 9 through 15 were produced from DIRECT in this fashion. They were selected to show a representative sampling from the wide variety of results. The predicted values for each case are shown in the upper left hand corner of each figure. These, and any other DIRECT graphic output can be verified by comparing the observed and tabulated values shown in the graphic against the associated input values found in lhs.dat, dikedata.txt, driftdata.txt, and the rules for dike overlay described in the previous section.

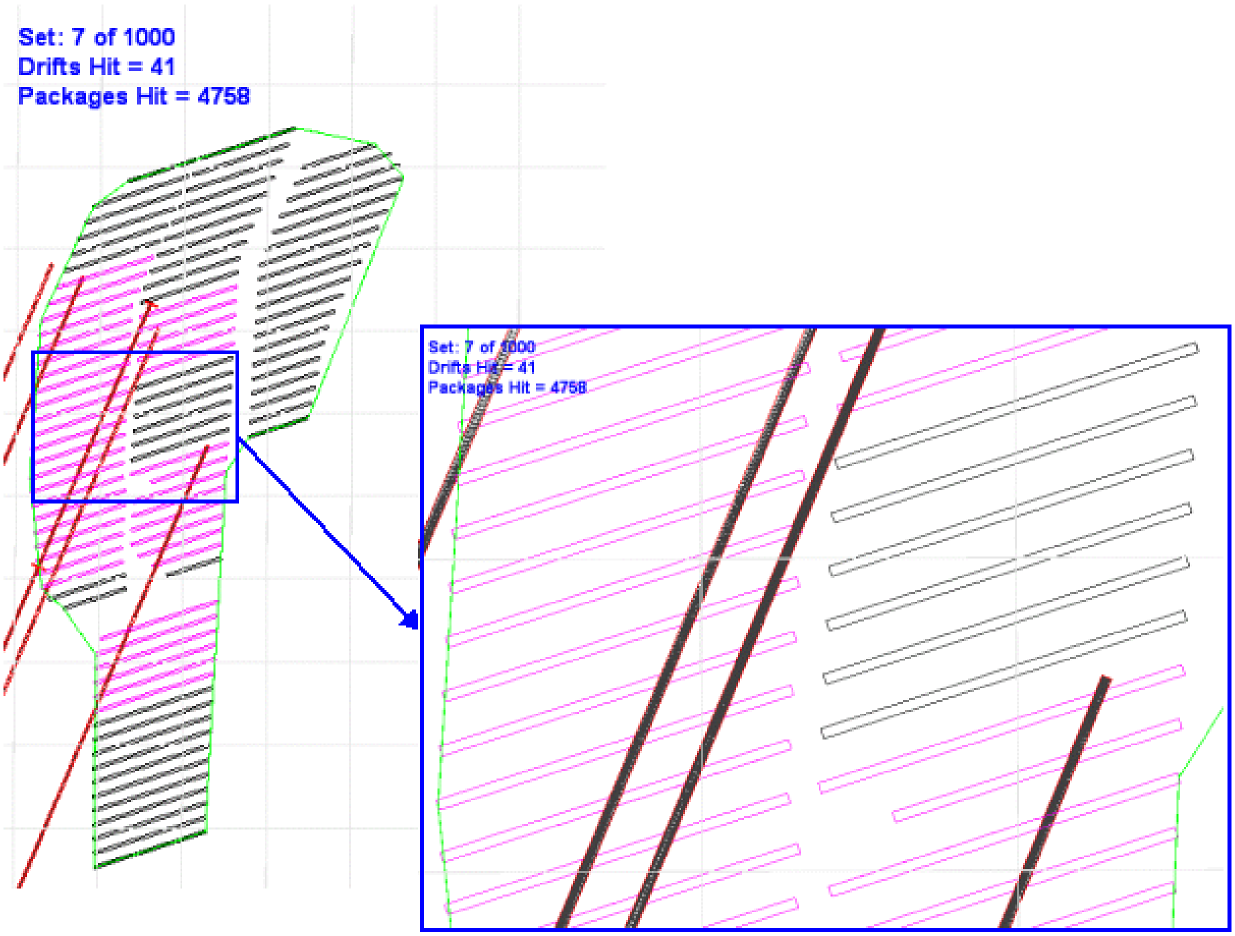
The figures below have special features that require consideration prior to result checking or other review. First, the grid overlay in each figure has an even spacing of 500 m in both directions. However, this grid is not correlated to any other system, such as Nevada State Plane coordinates. In any event, it can be used to help confirm sampled geometry parameters. Dikes are pictured in red and drifts are shown in gray. Any drift that is calculated to be intersected by a dike is changed to a magenta color. In addition, the thicknesses of the pictured dikes and drifts are all set at 16.5 m, in accordance with the previous discussion on bounding boxes. Due to the small scale, figures as shown may be misleading. For all of the sample figures below, a zoomed image is also supplied, in order to clarify areas of ambiguity. Note again that, using DIRECT, the user can look in detail at any location of interest.

Finally, the remaining graphic features expedite checking of parameters. The green line represents the perimeter of the repository as fed into DIRECT. This line is not intended to represent any formal perimeter boundary. It simply represents the 'track' along which the anchor point position is placed, following LHS sampling. The anchor point is shown as a short red line that is orthogonal to the current dike angle and which intersects the green perimeter line. The second short red line represents the end of the anchor extension. These short red lines are produced in part through use of the shape file diketest1.dts.



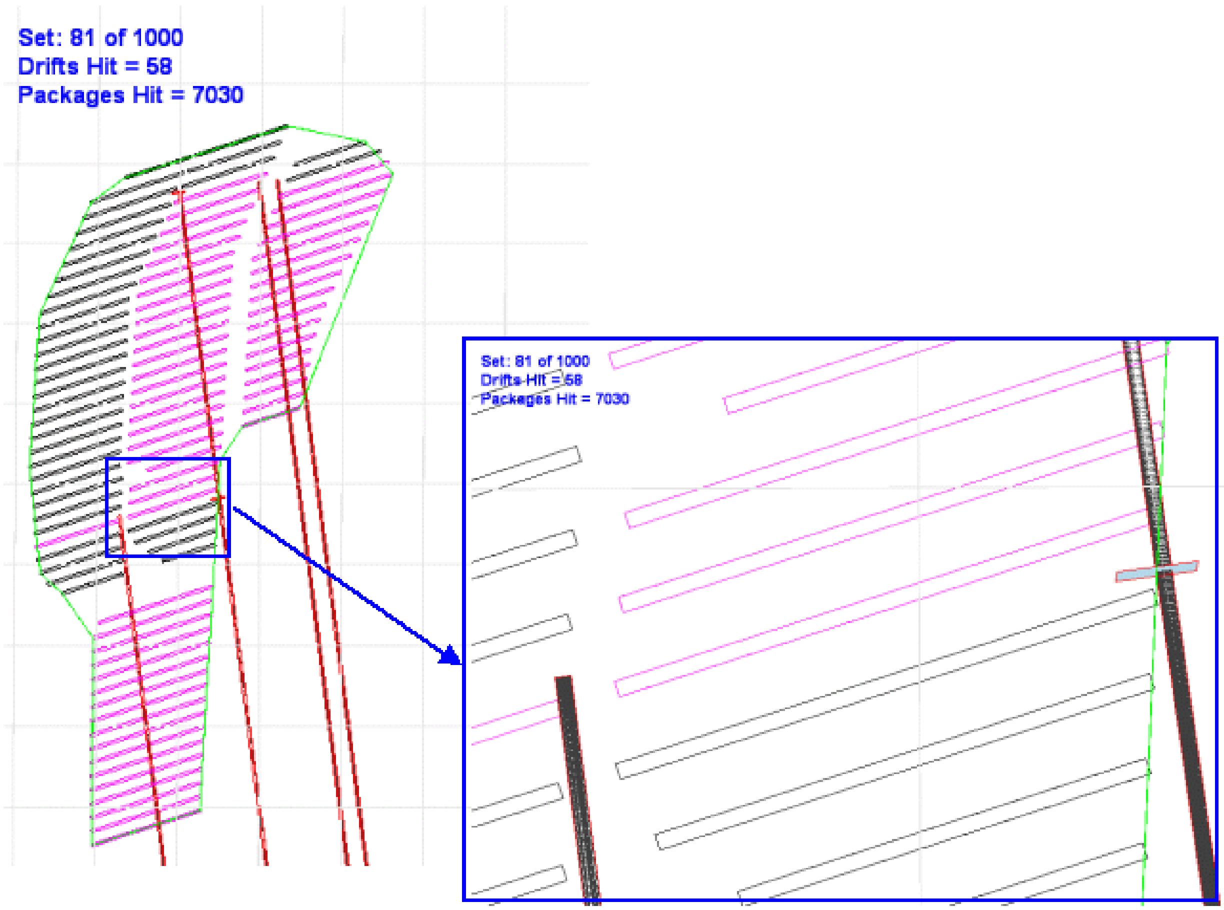
Modified output data for illustration: DTN# SN0402T0503303.004 [167515]

Figure 9. Selected screen captures of DIRECT results for replicate 3, set 1.



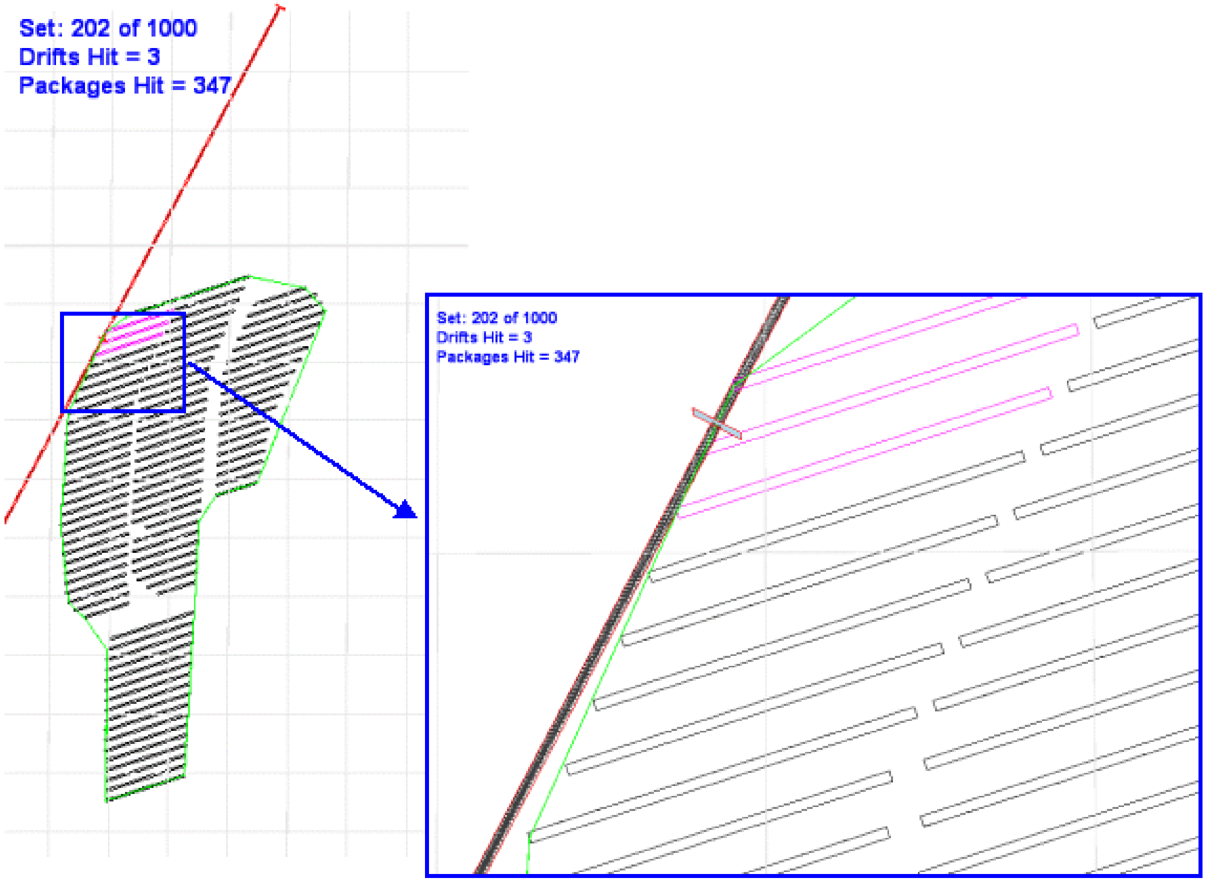
Modified output data for illustration DTN# SN0402T0503303.004 [167515]

Figure 10. Selected screen captures of DIRECT results for replicate 3, set 7.



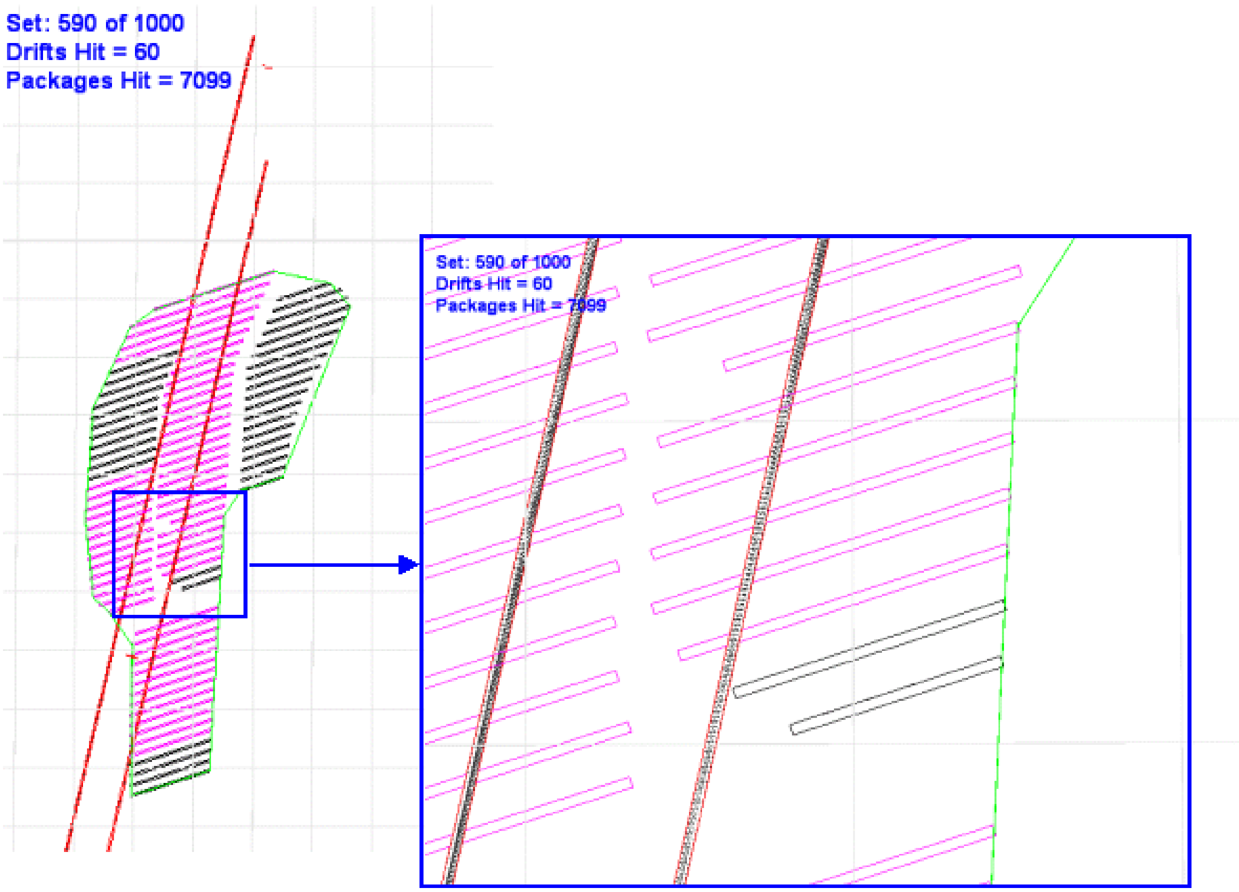
Modified output data for illustration DTN# SN0402T0503303.004 [167515]

Figure 11. Selected screen captures of DIRECT results for replicate 3, set 81.



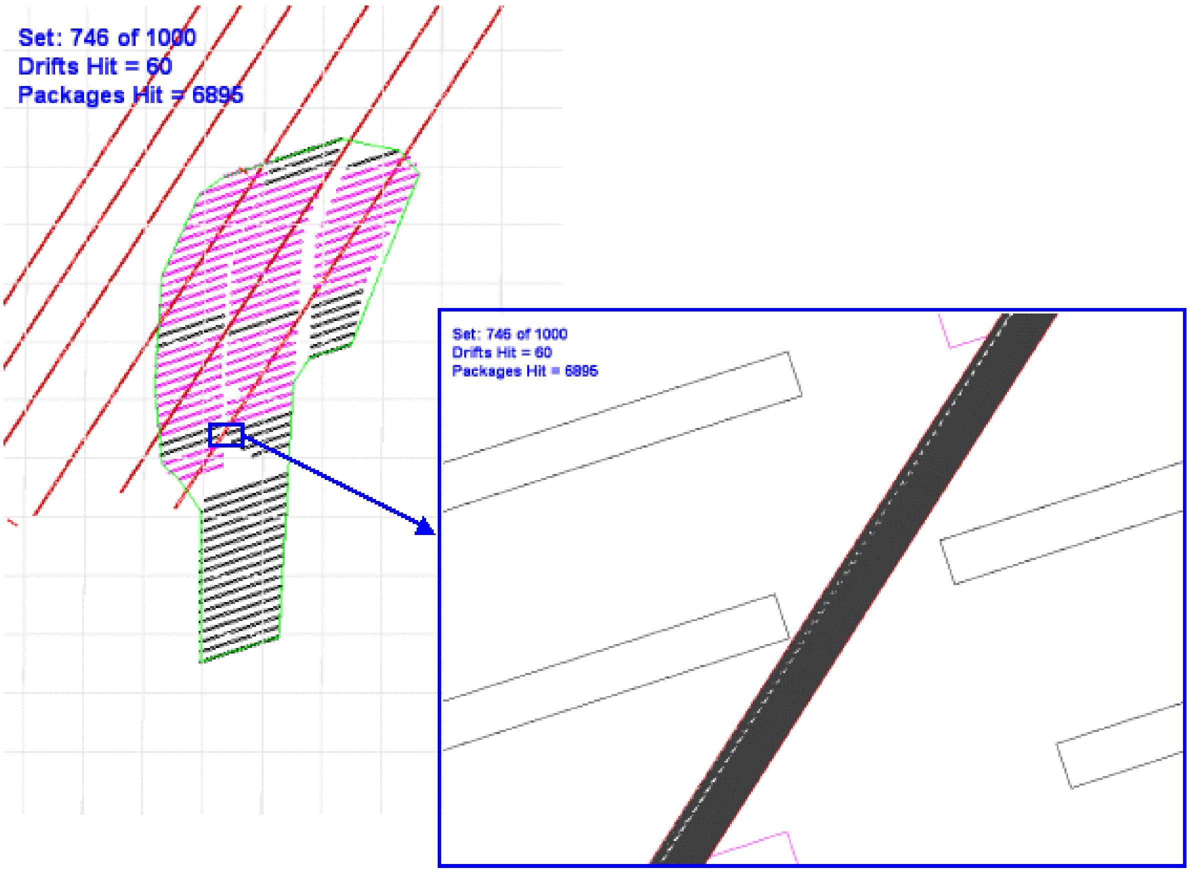
Modified output data for illustration   DTN# SN0402T0503303.004 [167515]

Figure 12. Selected screen captures of DIRECT results for replicate 3, set 202.



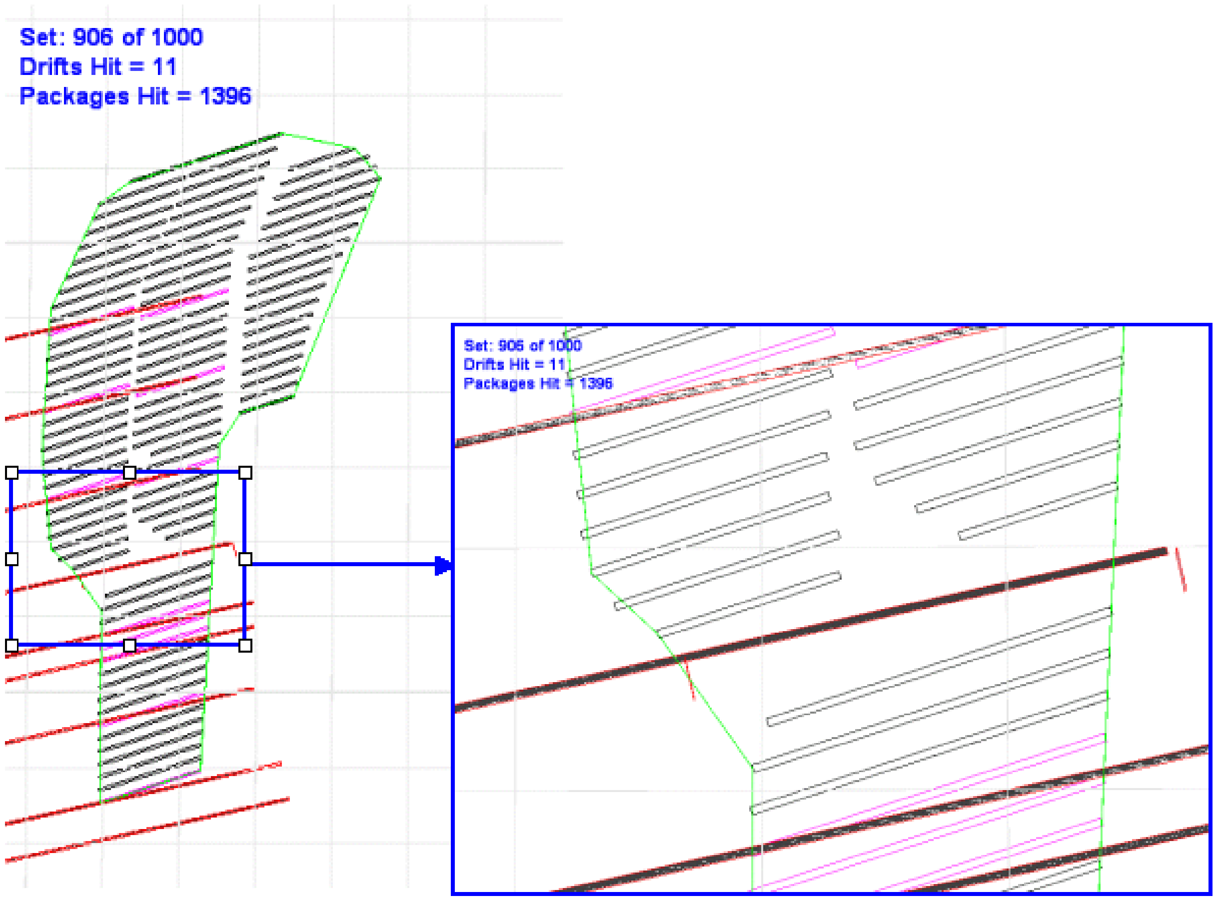
Modified output data for illustration   DTN# SN0402T0503303.004 [167515]

Figure 13. Selected screen captures of DIRECT results for replicate 3, set 590.



Modified output data for illustration   DTN# SN0402T0503303.004 [167515]

Figure 14. Selected screen captures of DIRECT results for replicate 3, set 746.

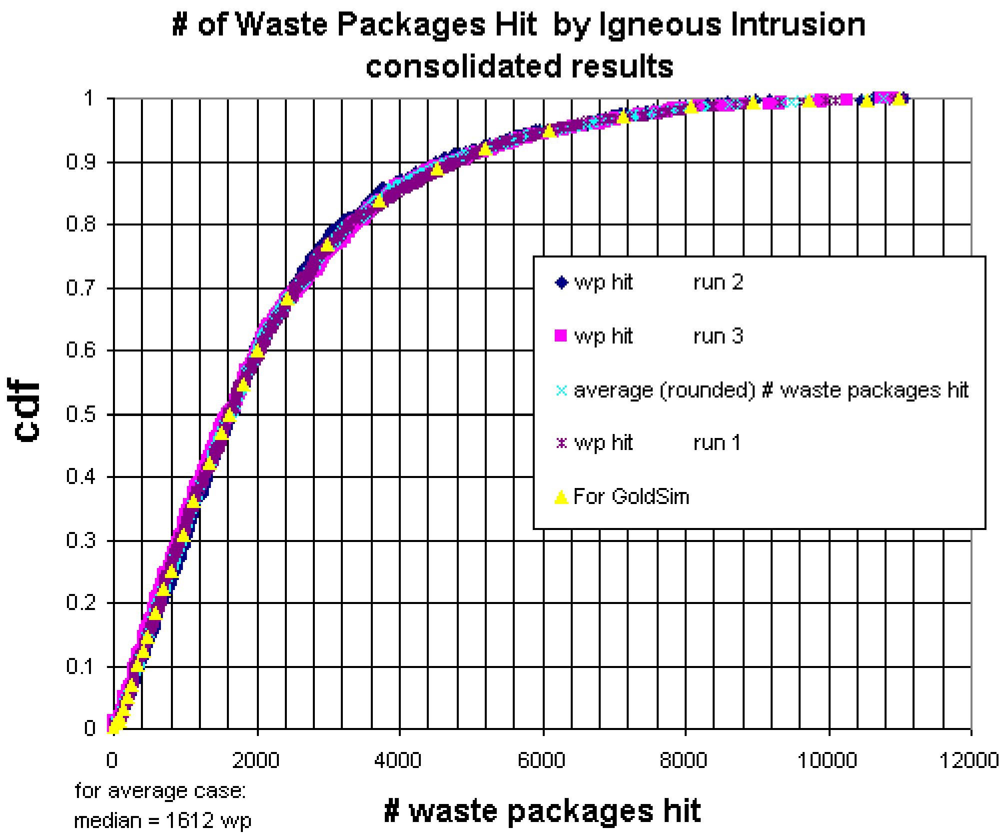


Modified output data for illustration   DTN# SN0402T0503303.004 [167515]

Figure 15. Selected screen captures of DIRECT results for replicate 3, set 906.

The results from three runs of DIRECT (using the three different LHS replicate files) are included in the files results_1.txt, results_2.txt and results_3.txt, respectively, in Attachment I, as well as in the DTN # SN0402T0503303.004. A complete set of graphics for all 3,000 runs is included at the same source.

Those results from the three replicates are combined and integrated via direct averaging into a single CDF, as shown in Figure 16 below. Details are documented in the worksheet "DikeSwarmCDF" of the spreadsheet "ANL-MGR-GS-000003_results.xls", included in the DTN # SN0402T0503303.004. Note that the median value is 1,612 waste packages hit, out of a wide range of results, from essentially zero to nearly the entire waste package inventory. The "For Goldsim" category is a CDF extracted from the integrated CDF, for use by Goldsim users.



Output data: DTN # SN0402T0503303.004 [167515]

Figure 16. CDF results for Igneous Intrusion case.

6.4 NUMBER OF WASTE PACKAGES HIT BY VOLCANIC ERUPTION

A volcanic eruption could occur through the repository and result in the development of eruptive conduits. As described in Section 6.3 of *Characterize Eruptive Processes at Yucca Mountain, Nevada* (BSC 2003 [166407]) that process could follow these steps:

1. A tabular dike vertically penetrates upward through the repository and reaches the surface.
2. Irregularities in the dike promote the evolution of one or more conduits, remaining along the generally planar boundaries of the dike.
3. The conduit transmits all material in its path upward to the surface. This includes waste from failed packages if they are intersected.

The analysis of the number of waste packages hit resulting from a volcanic eruption, considers a distribution of volcanic conduits, which are associated with a single volcanic event that affects the repository. Each conduit creates a circular profile through the repository, damaging any intersected waste packages and pulling waste to the surface.

The distribution of conduit diameters is adapted from DTN # LA0311DK831811.001 [166301], as shown in data row 1 (Conduit Diameter) of Table 1. That distribution is characterized by a minimum of 4.5 m, a mode equal to 50 m, and a maximum value equal to 150 m. For simplicity of binning in the distribution process, the minimum conduit diameter used in this analysis is set to 5.0 m. This also adds a slight conservative bias to the results.

As described in Section 5.2, all conduits in the same realization have the same sampled diameter. Also, it is worth noting that the minimum spacing between conduits, as developed in the PVHA (BSC 2003, Table II-13 [163769]), is 460 m . Given a maximum conduit diameter of 150 m, there is no possibility within this abstraction for conduit overlap.

In this abstraction, and as discussed in Section 5.3, the number of waste packages intersected by an eruptive conduit is treated as the product of conduit area times the average waste package density within the repository. The average waste package density is calculated by dividing the total planned number of waste packages by the total planned active repository area, including pillars. That approach is supported in part by the facts that the waste packages are uniformly distributed along each emplacement drift, and those emplacement drifts are evenly spaced within the repository footprint. In other words, the waste packages are relatively evenly spaced in two different directions (therefore anisotropic) throughout the repository. When considered over the scale of the entire repository, this leads to a relatively uniform waste package density, which supports the use of an average value.

This abstraction allows for simplifications to the analysis. The most important simplification is that there is no need to specifically consider the actual location of any particular emplacement drift, pillar, or waste package.

The number of waste packages damaged by a system of eruptive conduits is treated as a joint probability, dependent on both the number of conduits and the diameter of the conduits. Table 19 of BSC 2003 ([163769], Section 6.5.3) contains various distributions, based on different approaches, for the number of conduits associated with a dike system intersecting the repository. The approaches differ by several factors, including the degree of randomness versus the tendency towards a constant conduit spacing, and the degree of correlation between conduit number and dike characteristics. The distribution for the Mean Hazard, Final Composite Conditional Probability represents a composite of these different approaches, and is used in this analysis. That distribution has 14 bins, ranging from 0 to 13 conduits, with the maximum likely number as 1 conduit. Table 4. reproduces this distribution, with the accompanying source DTN number.

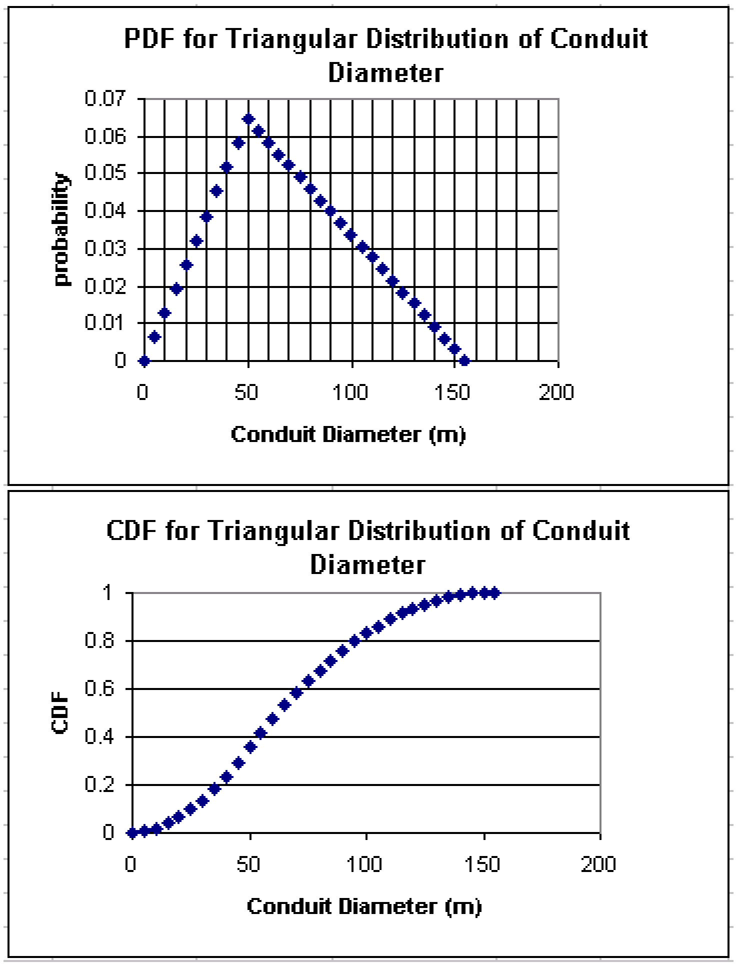
Table 4. Mean hazard probabilities for number of eruptive centers.

Number of Eruptive Centers within Repository	Final Composite Conditional Probability
0	0.218
1	0.567
2	0.108
3	0.0430
4	0.0238
5	0.0163
6	0.0101
7	0.00699
8	0.00335
9	0.00144
10	0.00092
11	0.00080
12	0.00045
13	0.00005

Source: BSC 2003, Table 19 [163769] DTN: LA0307BY831811.001 [164713]

Notably, the distribution, which allows as many as 13 conduits to penetrate the repository, has a conservative bias, since as Figure 19 of BSC 2003 [163769] documents, and as accompanying text indicates, the experts did not expect more than five eruptive centers to form from any local volcanic event, no matter how many dikes were associated with it.

The distribution for conduit diameters is taken from the DTN LA0311DK831811.001 [166301]. It is described as a triangular distribution with a most-likely (mode) value of 50 m, a minimum value equal to the host dike thickness of 4.5 m and a maximum value of 150 m. The development of this distribution is detailed in the work area titled "Auxiliary 1", starting on row 75 in the 'auxiliary' worksheet of spreadsheet ANL-MGR-GS-000003_results.xls. Attachment II of this document contains the information to acquire this spreadsheet from the Technical Data Management System (TDMS). The distribution has been modified slightly from the above guidelines, such that the minimum diameter is set at 5 m instead of 4.5 m. The change facilitates a more even distribution of bins, and also has a mild bias towards overestimation of the number of waste packages hit, as described previously. Bins are set at constant 5 m increments. This distribution for conduit diameters is shown in Figure 17.



Output data: DTN # SN0402T0503303.004

Figure 17. PDF and CDF of conduit diameter distribution.

A preliminary CDF was made that addresses only the number of waste packages hit as a function of conduit diameter. The calculations for this distribution are detailed in the worksheet "ConduitPrelimData" of the spreadsheet ANL-MGR-GS-000003_results.xls. Attachment II of this document contains the information to acquire this spreadsheet from the TDMS. Column A of that worksheet lists the conduit diameter bins. Column B contains the CDF values, which were calculated in "Auxiliary1" described earlier. Column C contains the calculations of conduit area, given the diameter value from column A. Column D calculates the number of waste packages hit, and column E computes the probability PDF for each bin. The resulting CDF is displayed in the adjoining graph on that worksheet. That graph shows a median percentile value of less than 10 packages. It's important to note that this CDF only considers the effect of one conduit.

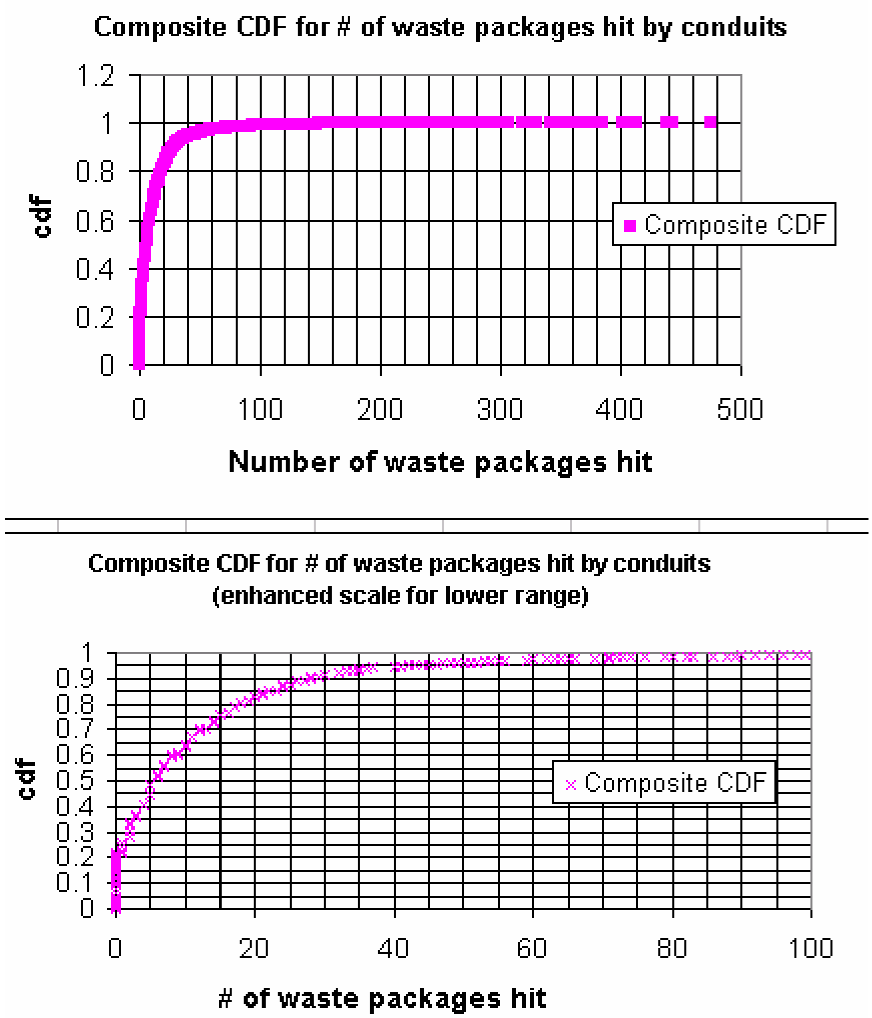
The combined effects of multiple conduits added to the effects of different conduit diameters are developed in the worksheet "ConduitCDF" of the spreadsheet ANL-MGR-GS-000003_results.xls. Attachment II of this document contains the information to acquire this spreadsheet from the TDMS. Column A contains the bins for conduit diameter. As before, there are 30 bins, all in constant 5 m increments. Columns B and C contain the CDFs and PDFs respectively for the conduit diameter distribution. This set of conduit diameter bins is repeated

14 times (the first time, plus another 13 times), as the distribution is integrated with the distribution for the number of conduits. The sum of probabilities in column C is therefore equal to 14.

Column D contains the elements for the number of conduits. As stated earlier, this distribution consists of 14 members with a constant incremental bin spacing of 1. Column E contains the corresponding PDF values. Since each component is added 30 times, through the integration with the conduit diameter distribution, the sum of the probabilities is approximately 30.

Column F contains the bins for the calculated numbers of waste packages damaged. These are calculated by multiplying the corresponding conduit areas by the corresponding number of conduits, by the waste package density factor. Column G contains the associated joint probabilities PDF, calculated by multiplying the values in columns C and E by each other, as defined by equation 3.

The adjoining graph depicts the resulting joint CDF. Less than 10 waste packages are damaged out of the median percentile of this distribution. In fact, the median value is approximately 5 waste packages. That graph is reproduced as Figure 18, with an expanded scale excerpt for the high slope early portion of the curve.



Output data: DTN# SN0402T0503303.004

Figure 18. Composite CDF for number of waste packages hit by conduits.

The so-called "dog leg" scenario is not considered in this analysis. In that scenario, as magma from a dike penetrates a drift, some of the magma hydraulically induces another vertical fracture set somewhere along the drift. The fracture set reaches the surface just ahead of the magma. This escaping magma represents in effect another conduit. In this scenario, the magma not only reaches the surface by another route, it also carries all waste in its path to the surface. The amount of waste could be considerable, since there are in general more than 100 waste packages per drift. However, that scenario has been eliminated from consideration in TSPA-LA through an extensive analysis (BSC 2004, Section 8.1.2 [167778]). That analysis considered the scenario in light of, among other things, expected pressures and temperatures (of both magma and host rock), and what would be required to trigger vertical fracturing. That analysis concluded that the necessary conditions for a dog leg scenario would not develop. Therefore the current approach in this analysis to estimating the number of waste packages hit due to eruptive conduits does not change.

6.5 ALTERNATE ANALYSES, WITH SENSITIVITY AND UNCERTAINTY STUDIES

With regard to the current analysis, uncertainties have been intrinsically accounted for by the nature of the Latin hypercube approach. In addition, drifts and dikes have both been treated as if they were at least three times wider than their sampled or assigned values. This generates a conservative bias in which more intersections are tallied than otherwise would be the case. This approach addresses potential additional minor uncertainties in dike positions.

An alternate approach was considered to evaluate the igneous intrusion scenario. The approach and its results are described in this section. Since the approach involves a fairly coarse abstraction of the entire problem, additional sensitivity analyses on the alternate theme have been conducted as well.

6.5.1 Alternate analysis

The alternate calculation for the number of waste packages hit by igneous intrusion was evaluated by first developing the abstraction approach, followed by implementation of that abstraction. As described in Section 4, available data includes repository design information, distributions for the lengths of dikes, the azimuths of these dikes, the number of dikes in a swarm, and the spacing of dikes within a swarm. The spreadsheet ANL-MGR-GS-000003_analysis_REV00I.xls (DTN: SN00402T0503303.005. [167724]) contains three worksheets covering the bulk of the analyses for this report. That spreadsheet is also included in a CD with this document as Attachment III.

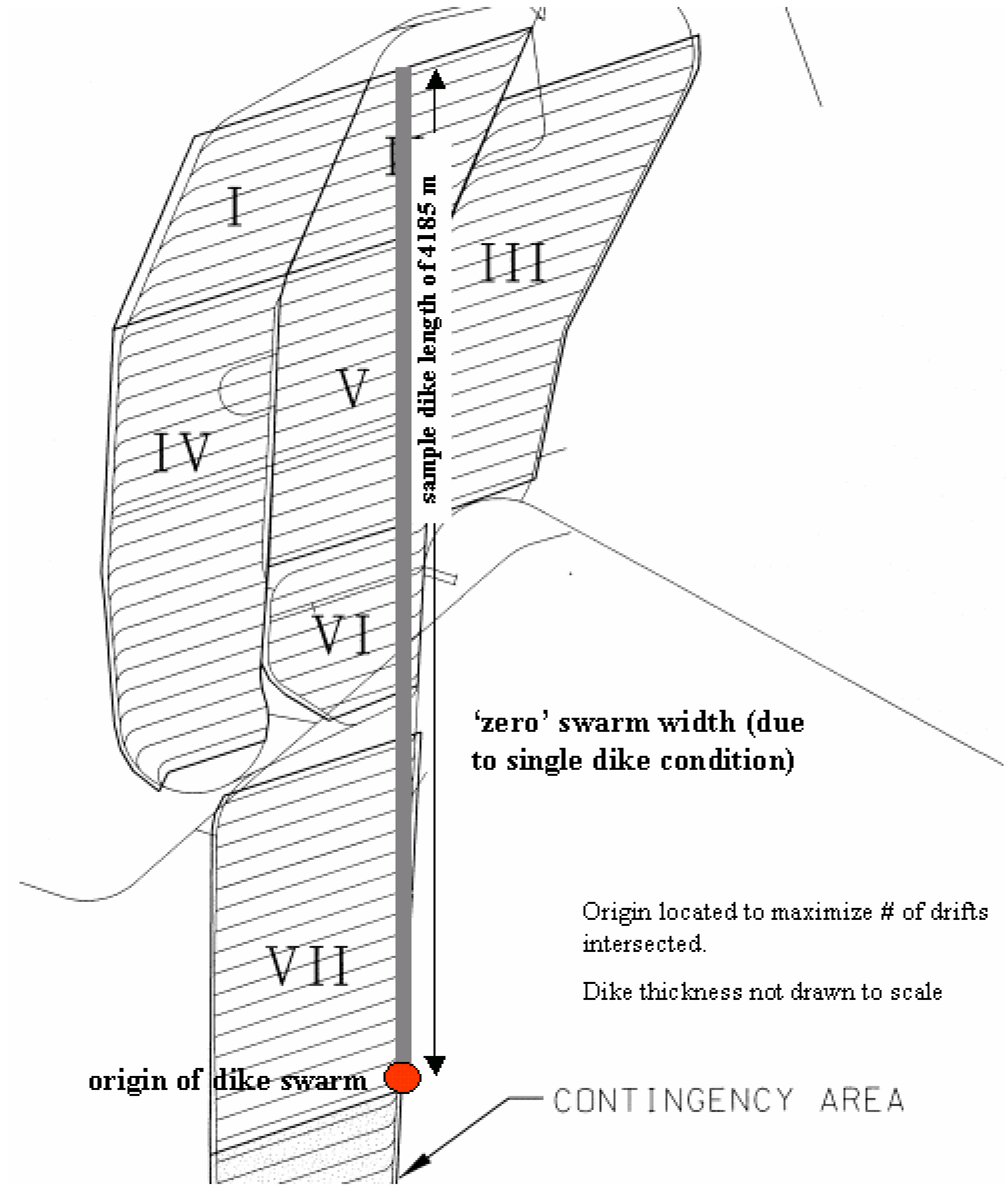
The alternate abstraction approach consists of a geometric treatment in which rectangular overlays, called 'swarm quads' are applied over the repository domain to represent various configurations of multiple parallel dikes of various lengths and angles. The variations in width and length of the swarm quad are applied from distributions for dike length and number of dikes, as described in the next section. Any repository drift that falls under the swarm quad overlay is treated as if it were intersected by a dike, as described in the following section.

6.5.2 Swarm Quad Abstraction

Dikes are elongate vertically oriented tabular bodies of magma which can extend laterally for kilometers from a mantle melting zone. More than one dike can result from the same mantle melt zone. A grouping of more than one dike related to the same magmatic event is called a swarm. If such dikes were formed in the vicinity of the repository, the repository could be intersected and a number of its waste packages would be damaged.

The extent of damage would be a function of many variables, including the length of the dikes in the swarm, the number of dikes in the swarm, the spacings between each dike, and the angles at which the dikes intersect the repository. This analysis takes a sub-population all of these variables into account. The analysis depends heavily on the probabilistic treatments of these variables contained in the *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* analysis report (BSC 2003 [163769]) and *Characterize Eruptive Processes at Yucca Mountain, Nevada.* (BSC 2003 [166407]).

The analysis is facilitated by a geometric abstraction of the system, as introduced in Figure 19. This figure illustrates the notion of a single dike intersecting the repository at a zero degree azimuth angle (due north). The red dot denotes the entry point of the dike. In this case, the entry point was purposely located to maximize the number of drifts which would be intersected for a dike of that angle and length. The dike would naturally extend to the south, but that portion falls within a contingency block and is outside the area of concern for this analysis.

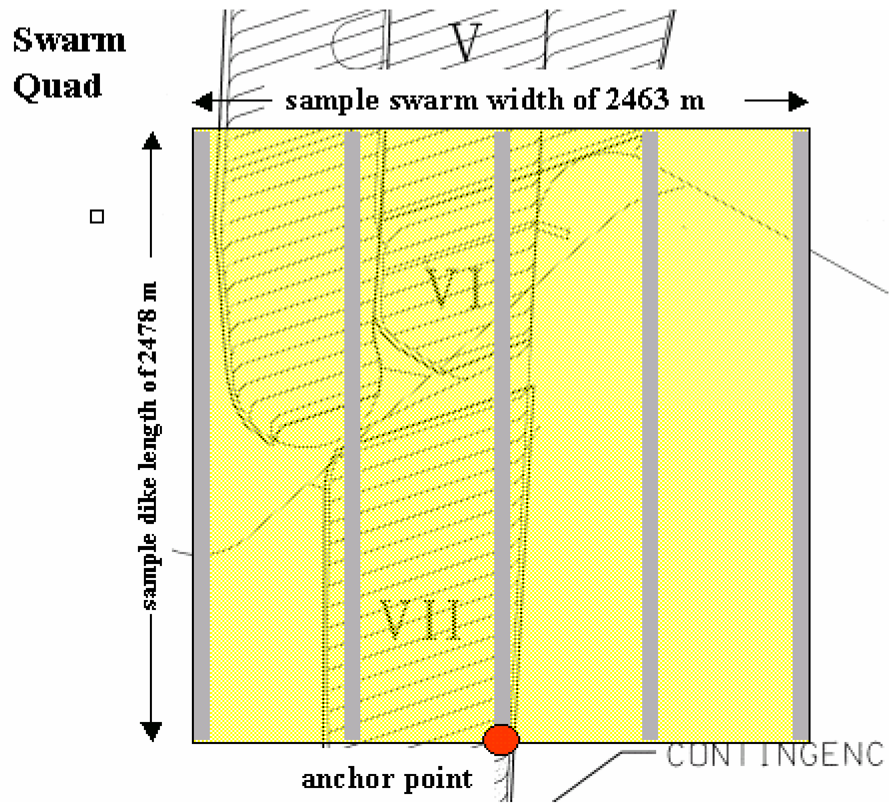


Input data. Modified from Figure 2 of IED: 800-IED-WIS0-00103-00Ab [164491].

Figure 19. Single dike at zero azimuth degrees example.

As discussed previously, dikes can occur in swarms, and the characteristics of a swarm, as they might apply to a repository scenario have been developed in the two analysis reports; BSC 2003 [163769] and BSC 2003 [166407]. Figure 20 shows the next stage of the abstraction. The 'swarm quad' represents a series of parallel equally spaced dikes (grey bars). The quad has the same azimuth angle as the selected dike azimuth angle. The value used for the number of dikes and for the equal spacing between dikes is sampled from two respective distributions (described in detail later in this section), and is converted to total swarm quad width (w). The value used for dike length is sampled from a distribution and used directly as swarm quad length (l).

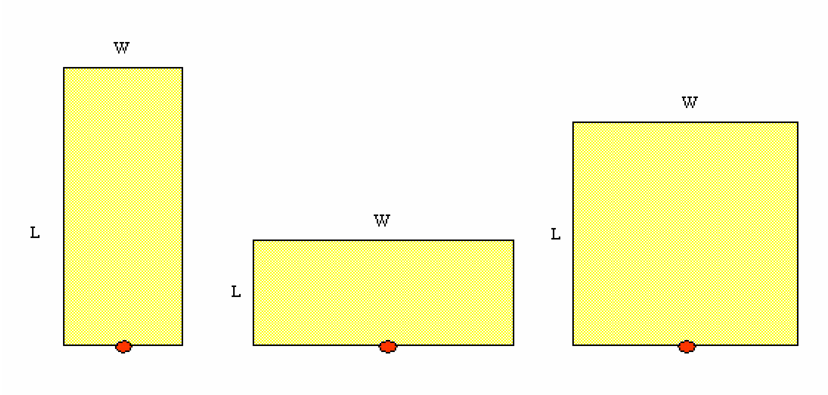
The same location is used for the anchor point as before. Swarms of dikes are treated as if they fan out equally from either side of the centerline, which emanates from the anchor point. If only one dike is sampled then there is no quad per se, but the calculation is treated no differently. In that case, the swarm width is assigned a zero value. If only two dikes are sampled, it can be assumed that they would be located at either boundary of the swarm quad. However, that is too literal an interpretation for this abstraction. In fact, this abstraction assumes that any drift falling within or intersecting the boundary of the swarm quad is impacted, even if the exact expected layout of dikes would not intersect the drift.



Modified from IED: 800-IED-WIS0-00103-00Ab [164491]. For illustration purposes only.

Figure 20. Swarm quad abstraction.

Since the length and width of the quad are based on distributions of variables, the geometry of the quad can vary, as illustrated in Figure 21.

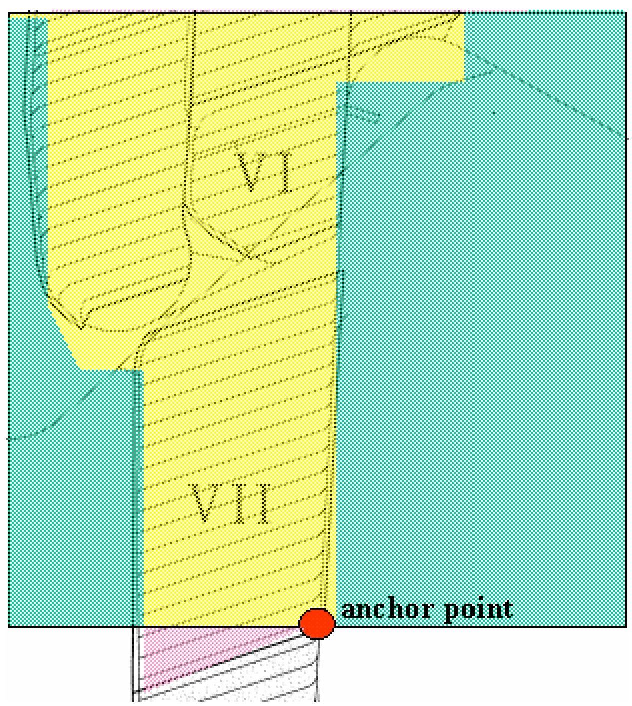


For illustration purposes only.

Figure 21. Swarm quad shape variety examples.

For any given azimuth angle, utilization of this abstraction involves determining the proper dimensions of the swarm quad and the anchor point position. The quad is superimposed over the repository diagram in the proper orientation, and the drifts which are intersected by the quad are tallied by hand. This is repeated enough times, given the same azimuth angle and anchor point, but varying width and length, to develop a coarse response surface of the number of drifts intersected. This surface can then be approximated by a bilinear equation, as shown subsequently in Section 6.5.3..

Figure 22 gives an example of a swarm quad overlay, given a zero degree azimuth and a sample width and length.



Modified from IED: 800-IED-WIS0-00103-00Ab [164491]. For illustration purposes only.

Figure 22. Swarm quad repository overlap example.

The green transparent zones show approximate areas included by the swarm quad abstraction, but which do not intersect drifts. The pink zone highlights areas of the repository which the quad does not overlay, and yet, due to the drift angle, are still impacted. They are impacted because of the assumption in Section 5.1, which states that for any drift intersected by a dike, all of the waste packages in that drift will be damaged. In both cases, the abstraction does a reasonable job of estimating the number of drifts intersected because the quad is abstracted to values which were based on the counting procedure used on selected swarm quads.

6.5.3 Modal Azimuth Angle Case

The analysis report *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada.* (BSC 2003 [163769]), contains a figure set (Figure 22) representing various distributions of possible azimuth angles through the repository. Azimuth angles are measured in degrees, going clockwise, from due North. Examination of the graph which plots mean azimuth angles, reproduced as Figure 3, shows a relatively narrow distribution, clustered around the modal value of 30 degrees. More precisely, the 30 degree angle is at the center of a bin that ranges from 27.5 degrees to 32.5 degrees (LA0303BY831811.001, file MLA-AZM.CDF [163985]). As part of the abstraction, this modal angle is used to represent the distribution. This allowed for a simplified treatment that still accounted for a relatively wide range of uncertainty (due to the variabilities in dike length and swarm width).

An anchor point was chosen which would lead to the maximum possible number of dike-drift intersections for any particular outcome. Figure 23 shows that point as a solid dot. A dike emanating from that anchor point, at the 30 degree angle, would intersect 33 drifts.

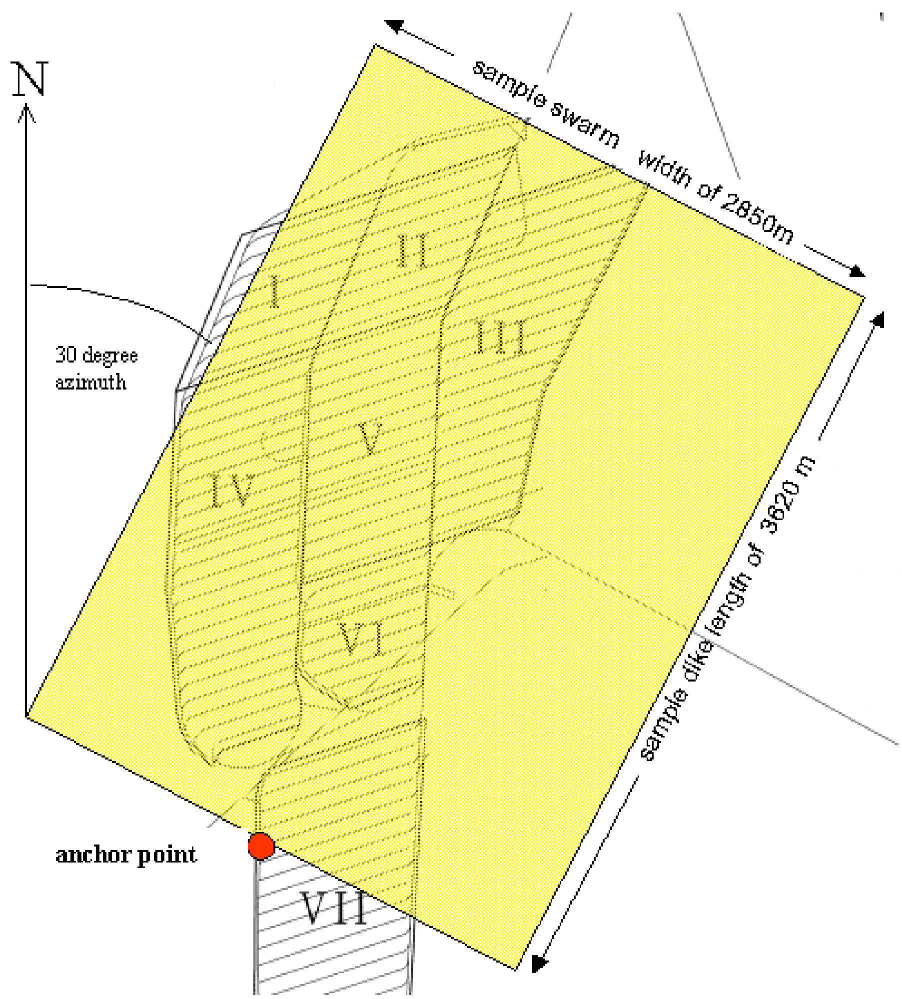
Any drift that falls within or intersects this swarm quad is treated as if it encounters a dike. As a simplifying abstraction, this allows the analysis to avoid explicit characterization of any particular dike - drift intersection. This abstraction is most justified for cases in which the dikes are oriented at least roughly perpendicular to the drifts. In those cases it actually takes potentially very few dikes to access the entire repository. In fact, a single dike could access a third or more of all drifts, given this orientation and configuration.

That would not be so for cases in which the dikes are roughly parallel to the drifts, as illustrated in Figure 24. In that example a series of equally-spaced, constant thickness, parallel dikes (gray bars) are considered which themselves are oriented roughly parallel to the orientation of the drifts. The figure demonstrates that a substantial number of drifts would be missed by many variations of this theme, particularly since the maximum individual dike thickness of 4.5 m (LA0311DK831811.001, [166301]) does not exceed the pillar width of approximately 81 m (BSC 2004 [167040]). In the illustrated example, only every 5th or 6th drift is accessed by a dike. Given this, and the fact that the probability of such a dike angle is relatively low (see Figure 3), there is no reason to further address this parallel orientation with regard to the number of waste packages hit.

The maximum number of drifts that can be intersected by a single dike line (at any angle) is 46, as shown in Figure 19. That could take place if the dike had an azimuth angle of zero degrees. Such an angle has roughly one seventh the probability of occurring as the modal 30 degree angle, as can be determined from Figure 3. Nonetheless, in the interest of exploring the uncertainty associated with this approach, the zero degree azimuth orientation is considered in Section 6.5.4.

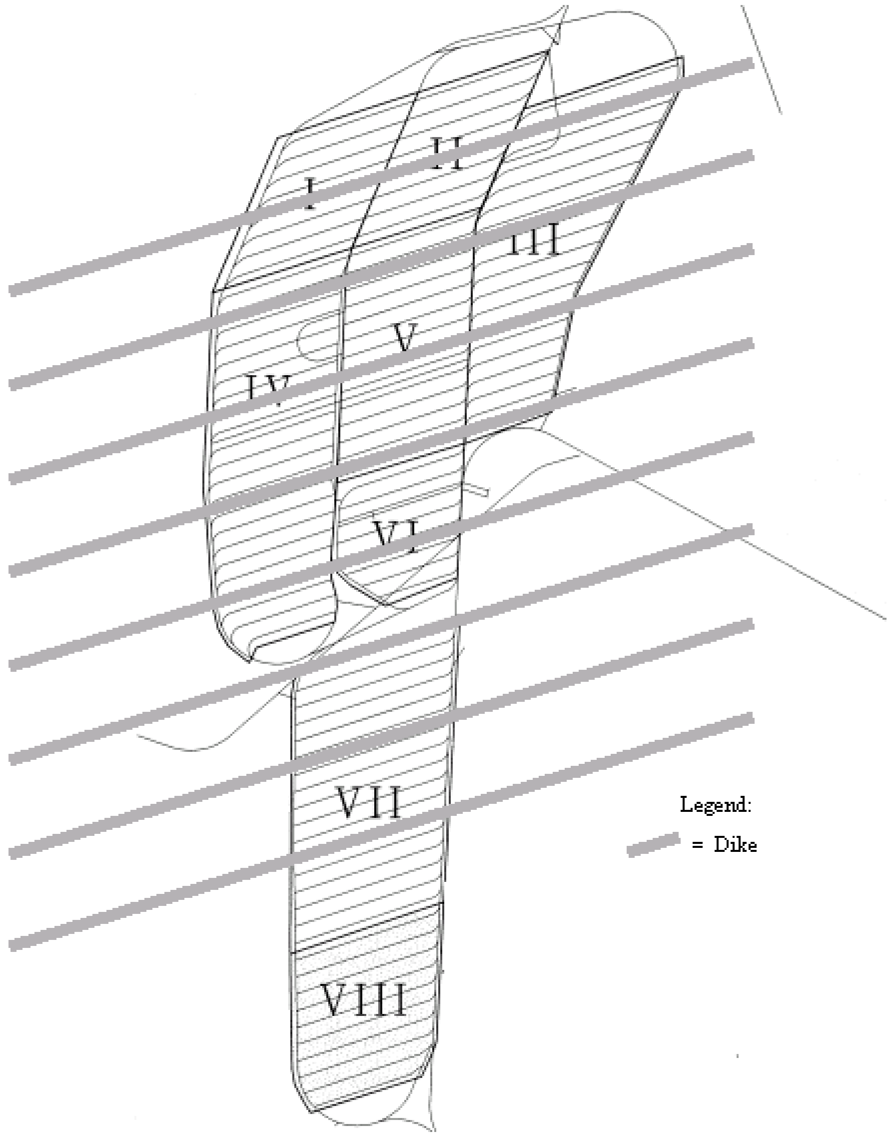
The remainder of this sub section documents the calculations that were developed to determine the number of waste packages hit for the 30 degree azimuth case.

The distribution of dike lengths was also adapted from the analysis *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003, [163769]). Specifically, the spreadsheet CCSM-LA.CMP (DTN#: LA0302BY831811.001)[162670] depicts integrated distributions of dike length, azimuth angle, and number of conduits. Only the dike length bins associated with an azimuth angle of 30 degrees were selected for this analysis. Therefore, the extracted distribution of dike lengths was re-normalized so that the total of all the probabilities summed to one. Dike length bins are in equal 50 m segments with total lengths ranging from zero to 4000 m. This length is approximately the maximum length of the repository in any direction. The source DTN contains bins for lengths greater than 4000 m, but those have been ignored, since they go beyond the maximum repository length.



Modified from IED: 800-IED-WIS0-00103-00Ab [164491]. For illustration purposes only

Figure 23. Description of alternate dike-swarm implementation.



Modified from IED: 800-IED-WIS0-00103-00Ab [164491] For illustration purposes only.

Figure 24. Example of dike swarm when azimuth angle is identical to that for drift azimuth angle.

As mentioned earlier, the spreadsheet ANL-MGR-GS-000003_analysis_REV00I.xls (Attachment III links this spreadsheet to the appropriate DTN) contains three worksheets covering the bulk of the analyses for this alternate calculation. The worksheet 'repository geometry' contains information on repository areas, drift lengths, waste package + spacing lengths, average number of waste packages per drift, total number of drifts, and total planned number of waste packages in the repository.

The worksheet 'DikeSwarmCDF' contains the calculations necessary to develop the cumulative distribution function (CDF) for the number of waste packages damaged when a swarm of dikes intersects the repository.

The swarm width distribution is divided into 10 bins and is shown in the above worksheet at columns D through G, rows 4 through 13. The development of the underlying supporting distributions is shown in detail in the areas labeled “Auxiliary 2” and “Auxiliary 3” of the worksheet ‘auxiliary’ of the same spreadsheet, and reproduced here in part as Tables 5 and 6. This development is derived in part from the distribution for the number of dikes in a swarm, which was assigned as a triangular distribution with a range from 1 to 10 and a mode of 3 (LA0311DK831811.001 [166301]). In addition, that reference provides the distribution of dike spacings, assigned as random uniform, ranging from 100 m to 690 m. Given the conditions that all dikes are parallel in a swarm, and that the spacing between each dike (for each dike length-swarm width combination) is a constant value, the transfer to a distribution for swarm widths is straightforward. Table 6 summarizes the swarm width distribution.

Table 5. Excerpt from Auxiliary 2 calculation. see Attachment III

	A	B	C	D	E	F	G	H
32	**Auxiliary 2**							
33	independent development of distribution of # of dikes in a swarm,							
34	based on latest version of BSC 2003, "Characterize Eruptive							
35	Processes at Yucca Mountain, NV" [161838]							
36	mode =	3	the analysis package considers a min of 1 and a max of 10.					
37	min =	0	This calc extends one to each end of range, to ensure that 1					
38	max =	11	and 10 have non-zero probabilities.					
39	bin width	1						
40								
41	bin	pdf	cdf					
42	0	0	0					
43	1	0.06061	0.0606061					
44	2	0.12121	0.1818182					
45	3	0.18182	0.3636364					
46	4	0.15909	0.5227273					
47	5	0.13636	0.6590909					
48	6	0.11364	0.7727273					
49	7	0.09091	0.8636364					
50	8	0.06818	0.9318182					
51	9	0.04545	0.9772727					
52	10	0.02273	1					
53	11	0	1					
54	sum	1						

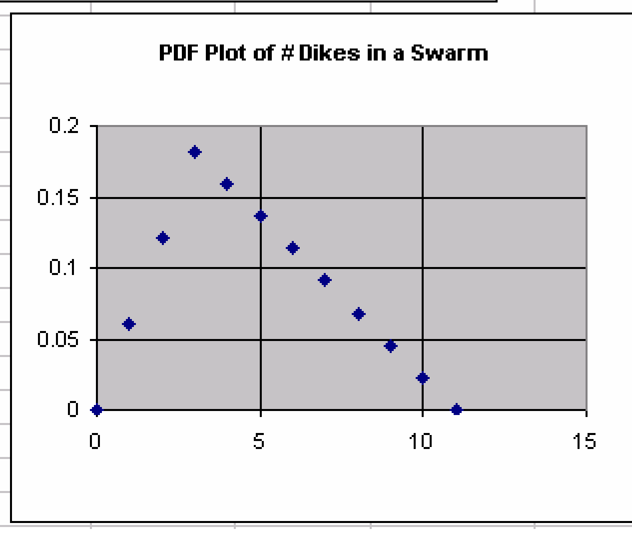


Table 6. Development of swarm width distribution. see Attachment III

Auxiliary 3

Independent development of distribution of swarm widths based on latest version of BSC 2003 "Characterize Eruptive Processes at Yucca Mountain, NV". [161838]
DTN: LA0311DK831811.001. [166301]

Row	# of Dikes	PDF	CDF	dike spacing	swarm width
78	1	0.06061	0.0606061	0	0
79	2	0.12121	0.182	461	461
80	3	0.18182	0.364	223	446
81	4	0.15909	0.523	567	1701
82	5	0.13636	0.659	684	2736
83	6	0.11364	0.773	557	2785
84	7	0.09091	0.864	222	1332
85	8	0.06818	0.932	534	3738
86	9	0.04545	0.977	337	2696
87	10	0.02273	1.000	133	1197

dike spacing calculated through Excel RANDBETWEEN function. However, after it was used, the function was turned off. Otherwise, any subsequent change to the spreadsheet anywhere, even to unrelated portions, will change the values initially calculated by RANDBETWEEN, making checking impossible.

Assumptions and Problem Setup:
1. dike spacings are assigned a random value from 100 to 690 m.
2. Actual location of a swarm dike not important. Assume that if sampled width is broad enough to reach an additional panel, that a dike will be there to intersect drifts in that panel.

An empirical basis function was developed to calculate the combined effects of swarm width and dike length, given a constant azimuth angle of 30 degrees. The equation was developed by evaluating limiting cases of dike length, swarm width, and repository dimensions:

$$z = Ax + By + Cxy + D \qquad \text{(Eq. 1)}$$

Where
z = number of drifts intersected
A, B, C and D are constant coefficients
x = dike length, and
y = swarm width

Details of the empirical approach are contained in the section "Auxiliary 1" of the worksheet 'auxiliary' of the same spreadsheet described in the previous paragraphs. This development is recreated here as Table 7.

Table 7. Excerpt from development of parametric relation between dike length, swarm width, and number of drifts intersected. see Attachment III

equation: Ax + By +Cxy + D =

test coefficients	
A	9.00E-03
B	0.006
C	3.89E-06
D	1

sample values to fit

x	y	Measured Z	Calculated Z	error	error square
0	3200	9	20.2	-11.2	125.44
0	0	1	1.0	0.0	0.00
3991	0	33	36.9	-3.9	15.36
3991	3200	92	105.8	-13.8	191.60
1818	3200	52	59.2	-7.2	52.01
2494	3200	75	73.7	1.3	1.64
711	1020	14	16.3	-2.3	5.49
1321	1020	31	24.3	6.7	45.50
1761	1020	35	30.0	5.0	25.38
2574	1020	53	40.5	12.5	156.05
3624	1020	65	54.1	10.9	118.21
			error bias	**-2.1**	27.14

x represents dike length
y represents swarm width
z represents # of drifts affected by x and y.
Relationships developed initially by applying bounding cases and intermediate cases graphically and counting number of intersections by hand.

the error bias is the sum of all the recorded errors in column H. The closer this number is to zero, the lower the bias towards over- or under-estimation

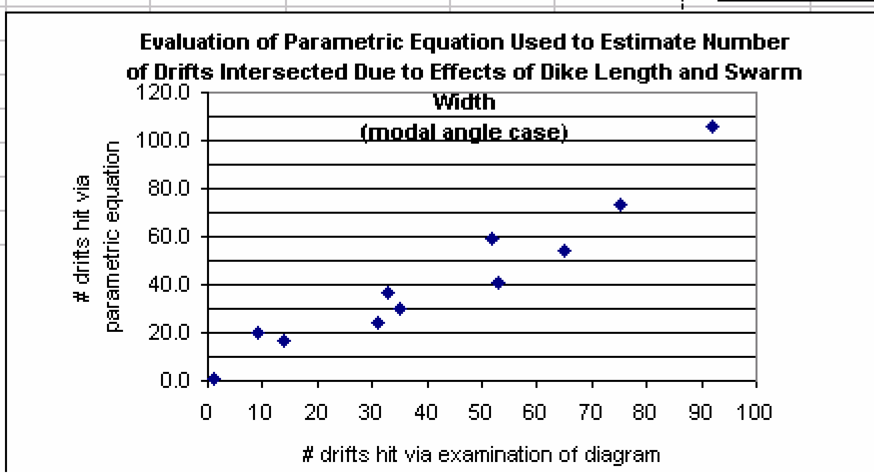
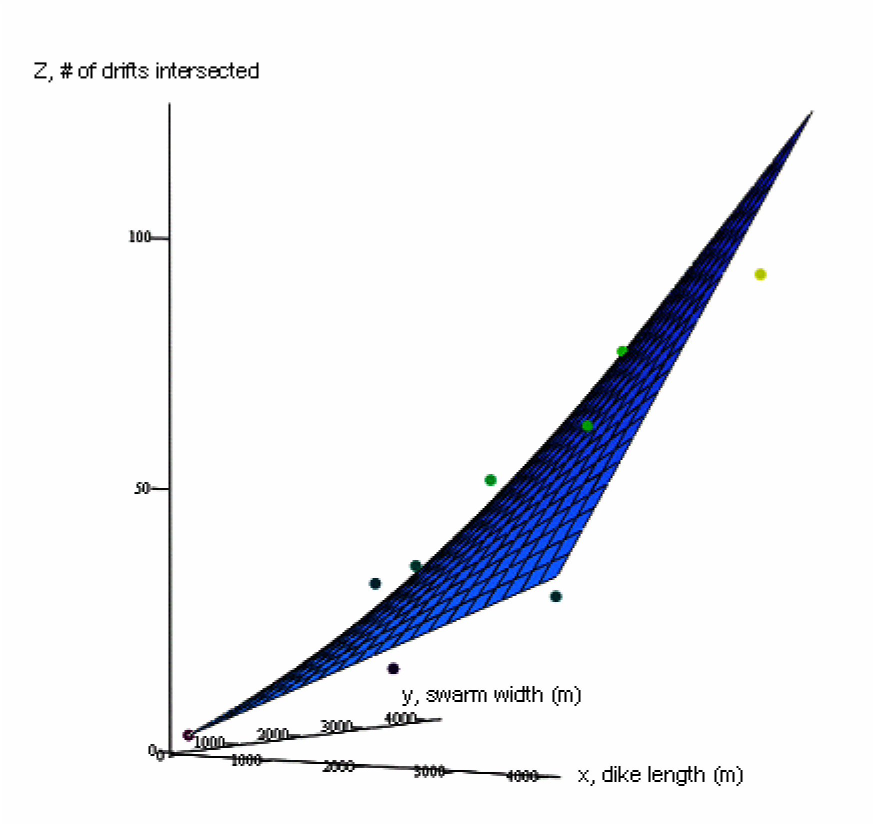


Figure 25. shows a representation of the response surface generated by the empirical basis function, along with the hand-calculated data points that the response surface is intended to approximate. The equation was checked against the hand calculations, as detailed in Table 7. The embedded graph in that table illustrates the fairly close relationship between the hand checked values and the predicted values. The predicted values can overshoot and undershoot the hand checked values, but appear to do this fairly equally, as shown by the low bias indicator of -2.1. The equation is considered accurate enough to serve its intended purpose. However, the potential number of drifts calculated by the equation is unbounded, while the repository has only 96 drifts. Therefore, limits must be applied in certain cases to prevent the prediction of more drift intersections than there are drifts.



For illustration purposes only. Green dots are data targets.

Figure 25. Illustration of response surface from development of parametric relation between dike length, swarm width, and number of drifts intersected.

From the number of drifts intersected, the number of waste packages hit can be directly estimated. The total number of emplacement drifts, excluding contingency drifts, is 96 (IED: 800-IED-WIS0-00103-00Ab, Figure 2, [164491]). The total number waste packages is 11,184 (800-IED-WIS0-00202-000-00B, Table 11, [167207]). An average number of waste packages per drift is calculated to equal 116.5. This calculation, and a verification calculation are detailed in the worksheet "repository geometry" of the spreadsheet ANL-MGR-GS-000003_analysis_REV00I.xls (see Attachment III). Therefore the estimated number of waste packages per drift is equal to 116.5, as shown in column B, row 11 of the worksheet DikeSwarmCDF. Initially, to prevent the accumulation of round off error, the number is not rounded. Later, the number is rounded up to 117 in the development of the CDF.

The analysis considers an integration of the two distributions of swarm width and dike length along with the empirical function, as well as ceilings which are applied to prevent overestimation of drifts intersected and of waste packages hit.

Integration of two distributions results in a joint probability distribution. The CDF for a joint probability distribution is presented as equation 2.32 (page 29) of Haan, (1977) [100579] reproduced below:

$$F_{X,Y}(x,y) = prob(X \le x \ and \ Y \le y) = \sum_{x_i \le X} \sum_{y_j \le Y} f_{X,Y}(x_i y_j) \qquad \text{(Eq. 2)}$$

where *x* and *y* are two independent random variables, *i* and *j* are indices for those variables, *X* and *Y* and samples from the distributions of those variables, *F()* is the cumulative joint probability function and *f()* is the joint probability.

Since the random variables are independent, Guttman et al., (1982) [141885] shows in equation 6.7.3 (page 90 and paraphrased below to match previous notation) that the joint probability of any combination of the two variables is equal to the product of the independent probabilities of each variable:

$$f(x_i, y_j) = f_x(x_i) f_y(y_j) \qquad \text{(Eq. 3)}$$

As previously stated, the data and results are detailed in the worksheet "DikeSwarmCDF" of the analysis spreadsheet ANL-MGR-GS-000003_analysis_REV00I.xls and included as Attachment III. This worksheet in part implements equations 1 and 2 as applied to the independent distributions of dike length and swarm width. Column A consists of a repeating series of the dike length bin distribution. That distribution contains 81 bins equally divided into constant lengths of 50 m. This set of bins is repeated 10 times, in accordance with its integration with the swarm width distribution, which consists of 10 bins.

Column B contains the normalized probability density function (PDF) of intersection of dike length with repository, associated with each bin to the left. The sum of probabilities in this column equals 10, accounting for the fact that the distribution is repeated 10 times.

Columns C and D contain the associated bins and probabilities for swarm width. These bins are spaced according to the calculation shown in Table 9. The sum of probabilities in column D equals 81, reflecting the fact that each probability of the swarm width distribution is summed 81 times (since that is the number of bins in the associated dike length distribution).

Column E calculates the total number of drifts intersected by dike swarms via equation 1 above. Column F applies a ceiling cutoff to prevent the number of drifts from exceeding the given drift number of 96. Column G multiplies the number of drifts by the average number of waste packages per drift (116.5), then rounds up one, and column H applies another ceiling correction to ensure that the total number of waste packages hit doesn't exceed the current design maximum of 11,184 (800-IED-WIS0-00202-000-00B [167207]). The joint PDF is calculated in column I, using Equation 3 above.

Figure 26 is a graph of the calculated CDF for number of waste packages hit by a swarm of dikes. The range covers the gamut of possibilities; from virtually no waste packages hit, to the entire inventory being damaged. The 50th percentile shows approximately 3200 waste packages hit, compared to 1612 from the analysis of Section 6.3.

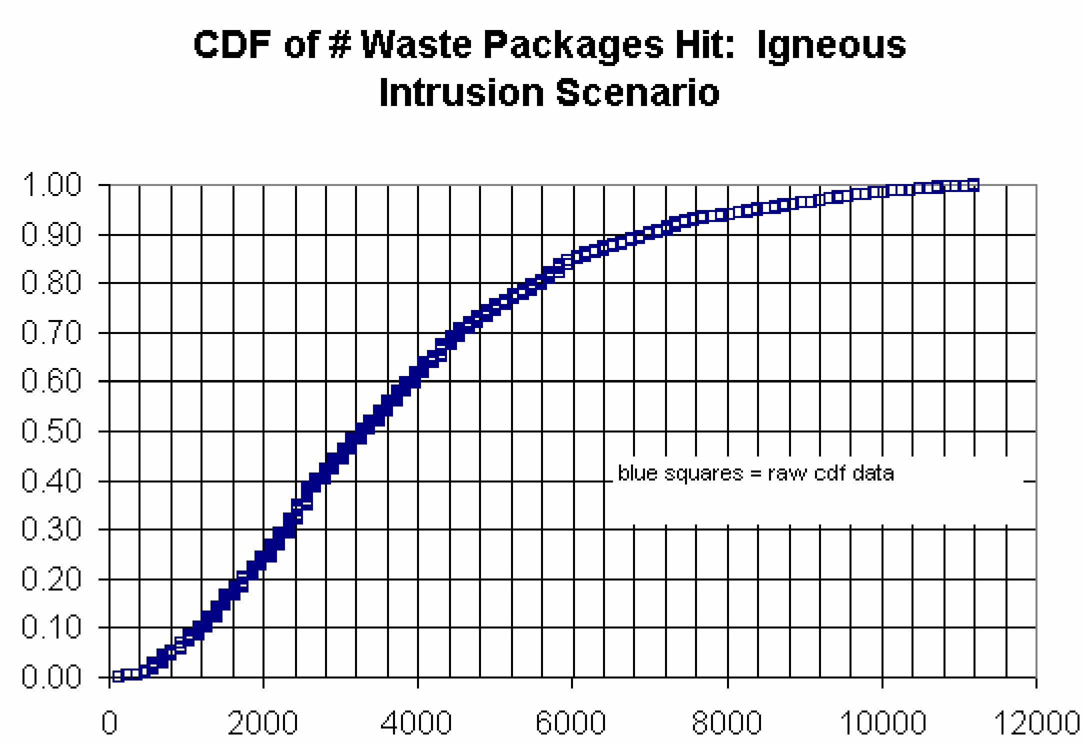


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Figure 26. Alternate base calculation of CDF of number of waste packages hit: Igneous Intrusion scenario.

This alternate analysis shows that the simplified abstraction approach produces an unrealistically high tally for the number of waste packages hit.

6.5.3.1 Sensitivity and Uncertainty Studies On Alternate Igneous Intrusion Analysis

The sensitivities of the alternate igneous intrusion analysis results were evaluated with respect to two parameters; the implementation of dike spacing and the treatment of the azimuth angle. These studies also address uncertainties by the fact that they consider different input distributions to the alternate analyses.

For the base alternate study, dike spacing was sampled from a uniform distribution, by using the Microsoft Excel RANDBETWEEN function. The values selected all had an equal probability of occurring, falling within the assigned range between 100 and 690 meters. Ten values were developed in this way, and were incorporated into the resulting distribution of ten swarm widths by multiplying each spacing by the number of dikes that it was matched to (See Attachment III, description of spreadsheet ANL-MGR-GS-000003_analysis_REV00I.xls, worksheet DikeSwarmCDF.)

This approach of using the RANDBETWEEN function was consistent with the distribution description for dike spacing as documented in (LA0311DK831811.001 [166301]) which states that the distribution of dike spacings was uniform and ranged between 100 and 690 m. The following sensitivity exercise looked at the effects on the number of waste packages hit for two alternate cases, one in which a constant dike spacing of 100 m was used and one in which a constant spacing of 690 m was used.

The treatment of the azimuth angle distribution has been discussed in Section 6.5.1. The base alternate analysis considered only the modal azimuth angle of 30 degrees. This sensitivity analysis evaluates the case for an azimuth of zero degrees. That particular angle was selected because it was shown that for a single dike at a specific origin point, more drifts were intersected under this angle than for the modal case. In the subsequent sensitivity analysis (Section 6.5.3.3), this angle is evaluated from the perspective of a swarm quad, and not just a single dike.

6.5.3.2 Dike Spacing Sensitivity Evaluation.

The spreadsheet ANL-MGR-GS-000003_analysis_REV00I_Sensitivity.xls is linked to the appropriate DTN in Attachment III, and includes worksheets "DikeSwarm_Sens1CDF_narrow_dike" and "DikeSwarm_Sens2_wide_dike". These worksheets evaluate the cases of a constant 100 m and 690 m dike spacing respectively. In each worksheet, the alternate distributions are developed first in the matrix defined by columns D through G and rows 3 through 13, including a header row. The 'swarm width' column in both cases is developed simply from multiplying the values in the #of Dikes column by the constant dike spacing considered. The resulting swarm width distributions are then integrated with the dike length distributions in the same manner as that used for the base case. In fact, modification of the swarm width calculations are the only changes from the base alternate case for this sensitivity analysis section.

For the DikeSwarm_Sens1CDF_narrow_dike case, this modification led to the distribution illustrated in Figure 27 below. As shown, a constant 100 m spacing, besides running counter to the recommended distribution from (LA0311DK831811.001, [166301]), leads to a CDF in which the median predicted number of waste packages hit is slightly under 2000. Notably, there are no predictions in this case where the number of waste packages hit reaches the maximum available quantity of 11,184. The maximum predicted number is approximately only 6,600.

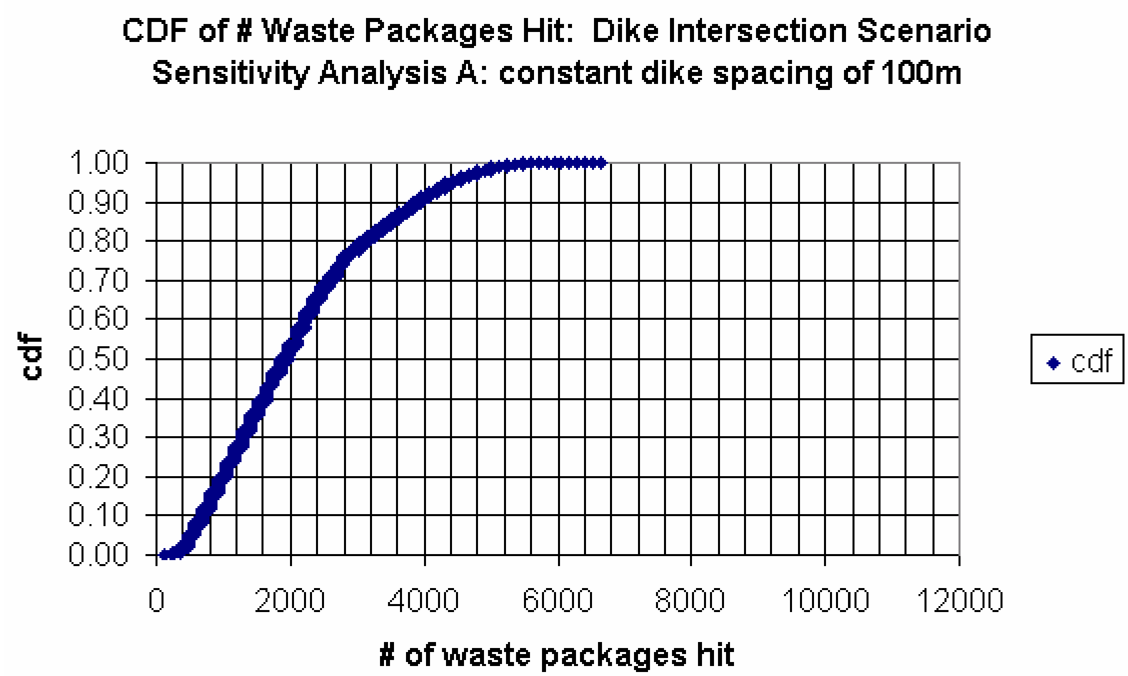

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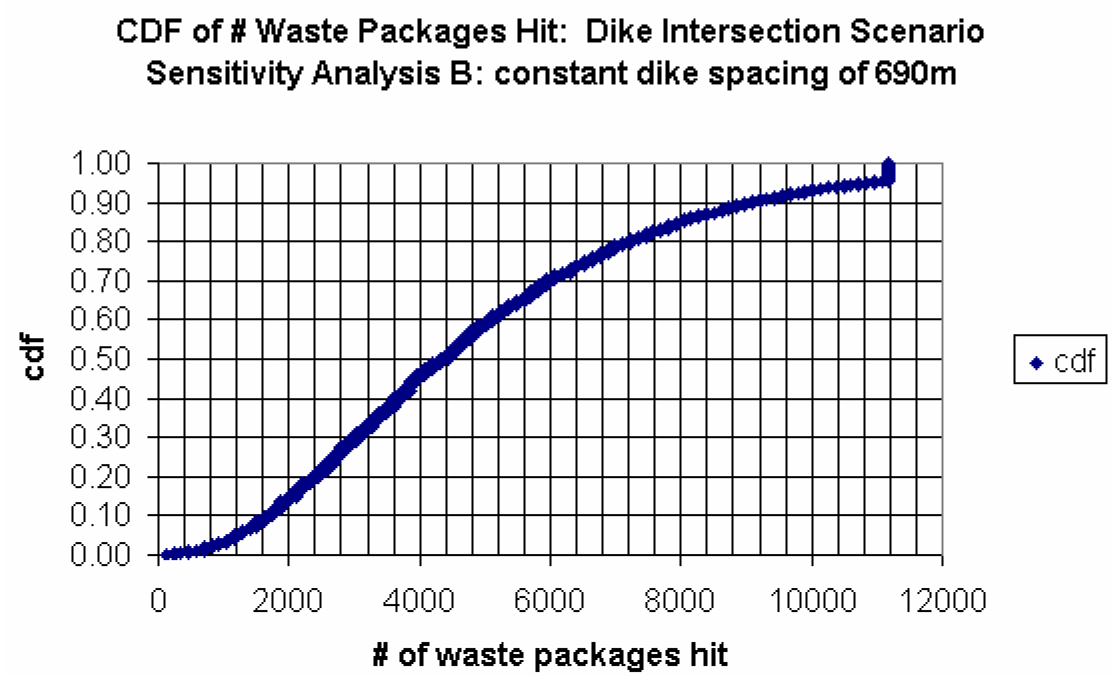
Figure 27. CDF of number of waste packages hit: constant dike spacing of 100 m.

For the DikeSwarm_Sens2_wide_dike case, the modification led to the distribution illustrated in Figure 28. As shown, a constant 690 m spacing, besides running counter to the recommended distribution from (LA0311DK831811.001, [166301]), leads to a CDF in which the median predicted number of waste packages hit is roughly 4400. Notably, there are also a significant extra number of predictions in which the number of waste packages hit does reach the maximum available quantity of 11,184.



DTN: SN0403T0503303.006

Figure 28. CDF of number of waste packages hit: constant dike spacing of 690 m.

These two results can be compared to the base alternate case (Figure 26), in which there appears to be little bias towards a high number or a low number of wastes packages hit. These sensitivity analyses do show that the predicted CDF is sensitive to the dike spacing distribution used. However, none of the alternate CDFs used here should replace the base case distribution of dike spacing. Use of an alternative distribution is not indicated for two reasons. First, neither single value in the sensitivity studies is justified to represent the recommended distribution from (LA0311DK831811.001, [166301]) of a uniform random distribution ranging from 100 m to 690 m. Second, none of the alternate analyses capture the recommended range of azimuth angles from (LA0303BY831811.001 [163985]). The base case implementation does honor both distributions, and more.

6.5.3.3 Dike Azimuth Angle Sensitivity Evaluation

The spreadsheet ANL-MGR-GS-000003_analysis_REV00I_Sensitivity.xls, included as Attachment III, contains worksheet DikeSwarm_Sens3_0Azimuth. That worksheet evaluates the case of a zero (strictly North-South) azimuth angle, as compared to the 30 degree azimuth angle addressed in the base alternate case. The CDF results are included here as Figure 29. As shown, the median number of waste packages damaged is approximately 2500, which is actually less than the median number for the base case alternate implementation (but of course, still much greater than the base implementation). This is likely due to the fact that the repository layout has a slight 'bend' to the northeast. When coupled with the 30 degree azimuth case (also a northeast trend), the swarm quad appears to more efficiently capture drift intersection possibilities, than for the zero azimuth case.

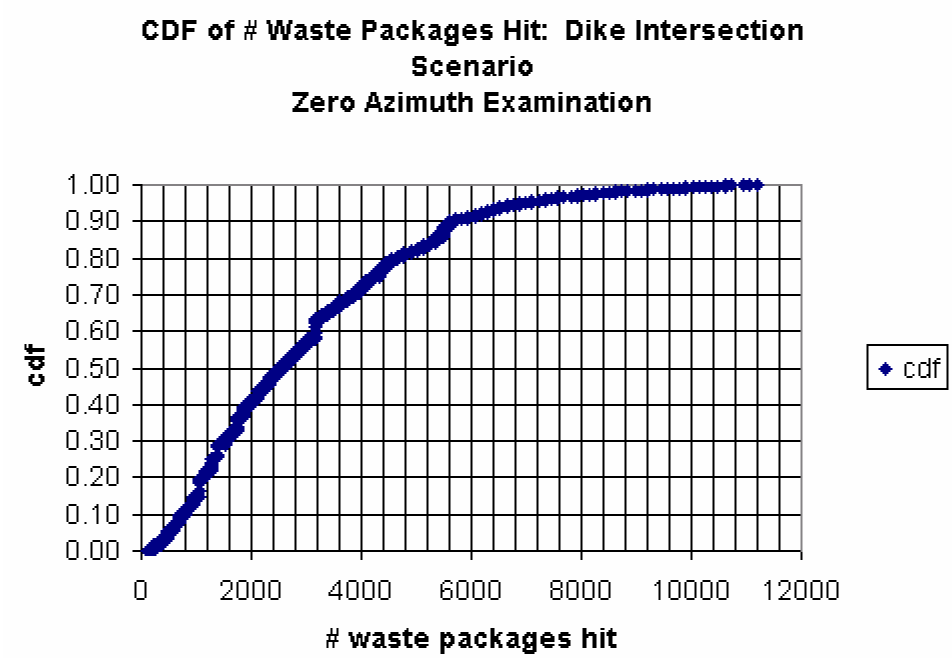


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Figure 29. CDF of number of waste packages hit: zero azimuth angle case.

Although this figure suggests that results are only moderately sensitive to dike azimuth angle, that argument should consider at least one additional factor. As with the 30 degree azimuth case, the PDF values used were normalized, thereby inflating the probability of all members of this population. In other words, both cases are conditional upon the probability of that particular angle. For cases in which dikes do reach the repository, the 30 degree azimuth case is far more likely than the zero degree case, as discussed earlier. Finally, it is anticipated that the sensitivity to azimuth angle will increase dramatically at higher angle values, as suggested by Figure 24.

6.5.4 Conclusions Regarding Alternate and Sensitivity Analyses

The alternate analyses and sensitivity studies produce a wide variety of results. None of the results led to median values from CDFs which were less than the base case result of 1612 waste packages hit. However, none of these alternate studies reflected the full array of qualified data and parameters that were explicitly included in the base study. Therefore, these alternate studies will not supersede the base analysis. Rather, they simply illustrate the relative sensitivity of the estimates of the number of waste packages damaged to variations in analysis inputs.

6.6 COMPARISON WITH SR RESULTS

The previous version of this analysis was the calculation report *Number of Waste Packages Hit by Igneous Intrusion*, (CRWMS M&O 2000 [153097]). In that calculation, two CDFs were developed for the case of swarms of dikes intersecting the repository. Neither is directly comparable to the results in this analysis package, because they utilized different assumptions, approaches, repository geometries and abstractions. For the first of those CDF calculations, among other important differences, it was assumed that damage to waste packages was limited to the area of the dike intersections plus a small fringe area. In that case, the median number of waste packages hit was 200. The second CDF calculation employed a similar assumption to Section 5.1 of this analysis, which states that all waste packages in a drift that is intersected by a dike will be damaged. In that CDF, the median value of 1,970 is similar in magnitude to the median value of the base result in this analysis (approximately 1,610 packages). Differences can be attributed to different repository designs and to the different approaches used to evaluate the problem.

The SR analysis did not directly calculate number of waste packages hit due to eruptive conduits. Therefore no direct comparison with the current analysis is possible. The previous analysis did develop a CDF for the number of waste packages hit, based solely on a distribution of conduit diameters, but that CDF was integrated into a different approach that is not comparable to the current one.

However the current analysis also developed a preliminary distribution for the number of waste packages hit based solely on a distribution of conduit diameters. That preliminary step is documented in the worksheet ConduitPrelimData of the spreadsheet ANL-MGR-GS-000003_results.xls. Attachment II links this document to the appropriate DTN. In that worksheet, column B, row 27 shows the approximate 50th percentile value (0.53) matched to column D of the same row which shows that the median number of waste packages hit for this preliminary step is seven. That is only slightly lower than the previous version's median value of 10 waste packages (table III-2, on page III-3, of CRWMS M&O 2000 [153097]).

The earlier analysis also anticipated a different treatment of its output. For the SR, given a no-backfill scenario, it was assumed that only three packages on either side of a dike would be fully damaged and that any remaining packages in the drift would only be slightly damaged (CRWMS M&O 2000, Section 3.10.2.3.1, [153246]. The resulting source terms for the numbers of damaged waste packages are therefore much less than the estimates that would result if all of the waste packages contacted by magma were considered to provide no further protection for the waste However the current analysis feeds into a treatment in which all waste packages hit are considered to be damaged. The rationale for this consideration is contained in Section 6.5 of (BSC 2003 [165002]). The resulting source terms for the numbers of damaged waste packages will be correspondingly greater.

7. SUMMARY AND CONCLUSIONS

The following sections provide summary details on analysis results, with direct mapping to exact locations in output spreadsheets. Also conclusions are described, with some comparison to previous results.

7.1 SUMMARY

An analysis was conducted to estimate the number of waste packages that would be damaged by igneous events using two scenarios. The first scenario investigated, known as the igneous intrusion scenario, was the case of one or more igneous dikes intersecting the repository. Dikes were given a distribution of lengths and swarm widths; relations were built between those parameters and the number of waste packages hit, and CDFs for the number of waste packages hit were calculated. The second igneous scenario investigated, known as the eruptive conduit scenario, considered the case of conduits forming in association with a volcanic eruption through the repository. A relation was built between the resulting conduit areas and the fraction of the repository area occupied by waste packages. This relation was used in conjunction with a joint distribution incorporating variabilities in eruptive conduit diameters and in the number of eruptive conduits that could intersect the repository.

Section 6.6 provides a description of how this analysis differs from the previous version (CRWMS M&O 2000) [153097], which was a calculation used in support of the TSPA-SR.

Primary outputs from this analysis report are a CDF for the number of waste packages hit by an igneous intrusion for use in TSPA analyses of the groundwater intrusion scenario and a CDF for the number of waste packages hit by an eruptive conduit for use in the eruptive scenario. Mapping to these CDFs is provided in the previous section.

The igneous intrusion analysis involved an explicit characterization of dike - drift intersections, built upon various distributions which reflect the uncertainties associated with the inputs. The eruptive conduit approach involved a simplified abstraction. Additional alternate calculations and uncertainties associated with this approach were addressed in Section 6.5.

This scientific analysis report also documents that the Features, Events, and Processes (FEPs) 1.2.04.04.0A *Igneous Intrusion Interacts with EBS Components* and 1.2.04.06.0A *Eruptive Conduit to Surface Intersects Repository* (BSC 2002) [158966] have been properly implemented into the TSPA-LA.

In addition, this scientific analysis report provides documentation for review by the NRC, based on acceptance criteria that will be used by the NRC to determine whether the technical requirements have been met, as identified in the *Yucca Mountain Review Plan*, Section 2.2.1.3.10.3 *Acceptance Criteria* [for 2.2.1.3.10 *Volcanic Disruption of Waste Packages*] (YMRP NRC 2003) [163274]. The criteria of concern are stated in Section 4.2 of this report as well.

The primary technical product output of this analysis activity is available through the TDMS at DTN# SN0402T0503303.004[167515] (also see Attachment II). Table 8 below contains the mapping to the results.

Table 8. Mapping of CDF Technical Product Outputs from ANL-MGR-GS-000003 to the Spreadsheet ANL-MGR-GS-000003_results.xls (DTN# (SN0402T0503303.004))

CDF Description	Worksheet subsection	row and column mapping
Number of Waste Packages Hit: Dike Intersection Scenario (section 6.3)	DikeSwarmCDF	start at row 6, column R finish at row 38, column S
Number of Waste Packages Hit: Eruptive Conduit Scenario (section 6.4)	ConduitCDF	start at row 11, column T finish at row 31, column U
Number of Waste Packages Hit: Preliminary CDF Based on Distribution of Eruptive Conduit Diameters, but not Integrated with Distribution for Number of Eruptive Conduits (section 6.4) This CDF is similar to the primary output eruptive conduit CDF that was provided to TSPA for the SR	ConduitPrelimData	see columns B and D

The secondary technical product output of this analysis activity consists of the alternate calculations and the subsequent sensitivity analyses. The first spreadsheet at this location (or, Attachment III) is labeled: ANL-MGR-GS-000003_analysis_REV00I.xls and contains three worksheets covering the bulk of the analyses for the alternative calculations. The actual CDF outputs of concern are mapped in Table 9.

Table 9. Mapping of Alternate CDF Results from ANL-MGR-GS-000003 to the Spreadsheet ANL-MGR-GS-000003_analysis_REV00I.xls Attachment III

CDF Description	Worksheet subsection	row and column mapping
Number of Waste Packages Hit: Dike Intersection Scenario alternate case (section 6.5.3)	DikeSwarmCDF	start at row 42, column R finish at row 70, column S

Additional sensitivity study CDFs were generated that are also included in Attachment III. They are tabulated below in Table 10.

Table 10. Mapping of Auxiliary CDF Technical Product Outputs from ANL-MGR-GS-000003 to the Spreadsheet ANL-MGR-GS-000003_analysis_REV00I_Sensitivity.xls
Attachment III

CDF Description	Worksheet subsection	row and column mapping
Number of Waste Packages Hit: Dike Intersection Scenario, Sensitivity Analysis 1 (section 6.5.3.1) considers a narrower and constant dike spacing within a swarm.	DikeSwarm_Sens1CDF_narrow_dike	start at row 23, column L finish at row 833, column M
Number of Waste Packages Hit: Dike Intersection Scenario, Sensitivity Analysis 2 (section 6.5.3.1) considers a wider and constant dike spacing within a swarm.	DikeSwarm_Sens2_wide_dike	start at row 23, column L finish at row 833, column M
Number of Waste Packages Hit: Dike Intersection Scenario, Sensitivity Analysis 3 (section 6.5.3.2) considers a zero degree azimuth angle for swarm orientation.	DikeSwarm_Sens3_0Azimuth	start at row 23, column L finish at row 833, column N

7.2 CONCLUSIONS

The igneous intrusion scenario shows a range of consequences, extending from virtually no waste packages damaged to nearly all waste packages in the repository. The 50th percentile value indicates approximately 1610 waste packages impacted, out of over 11,000 waste packages in the repository. This is less than the equivalent value from the previous version of this analysis (CRWMS M&O 2000, Section 6.2, [153097]) by approximately 360 waste packages. Differences can be attributed to a new repository design and to the new approaches used to evaluate the problem.

The prior report did not develop a CDF for number of waste packages impacted by eruptive conduits, therefore no exhaustive comparisons can be made for that scenario. For this analyses the median number of waste packages hit for the volcanic eruption scenario is less than 10.

8. INPUTS AND REFERENCES

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167992 AP-SIII.9Q, REV 1, ICN 3. *Scientific Analyses*. Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040301.0002.

166289 BSC (Bechtel SAIC Company) 2003. *Technical Work Plan: Igneous Activity Assessment for Disruptive Events.* TWP-WIS-MD-000007 REV 04. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031125.0006.

160313 BSC (Bechtel SAIC Company) 2002. *Scientific Processes Guidelines Manual.* MIS-WIS-MD-000001 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020923.0176.

166275 Canori, G.F. and Leitner, M.M. 2003. *Project Requirements Document.* TER-MGR-MD-000001 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030404.0003.

163274 NRC (U.S. Nuclear Regulatory Commission) 2003. *Yucca Mountain Review Plan, Final Report.* NUREG-1804, REV 2. Washington, D.C.: U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards. TIC: 254568.

159538 NRC (U.S. Nuclear Regulatory Commission) 2002. *Integrated Issue Resolution Status Report.* NUREG-1762. Washington, D.C.: U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards. TIC: 253064.

164786 AP-2.22Q, REV 1, ICN 0. *Classification Analyses and Maintenance of the Q-List.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20030807.0002.

100909 Kotra, J.P.; Lee, M.P.; Eisenberg, N.A.; and DeWispelare, A.R. 1996. *Branch Technical Position on the Use of Expert Elicitation in the High-Level Radioactive Waste Program.* NUREG-1563. Washington, D.C.: U.S. Nuclear Regulatory Commission. TIC: 226832.

8.3 SOFTWARE

In addition to the exempt software, the following codes were used in this analysis:

167794 SNL (Sandia National Laboratories) 2004. *Software Code: LHS.* V2.51. DEC ALPHA OPEN VMS AXP 7.3-1. 10205-2.51-00.

167795 SNL (Sandia National Laboratories) 2004. *Software Code: DIRECT.* V 1.0. PC, Windows 2000. 11121-1.0-00

8.4 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

163985 LA0303BY831811.001 *Characterize Igneous Framework Figures and Tables.* Submittal date: 04/07/2003

162670 LA0302BY831811.001 *Characterize Igneous Framework and Probability.* Submittal date: 02/05/2003

166301 LA0311DK831811.001 *Physical Parameters of Basaltic Magma and Eruption Phenomena.* Submittal date: 11/03/2003

164713 LA0307BY831811.001 *Characterize Igneous Framework Additional Output* Submittal date: 07/29/2003

8.5 TECHNICAL PRODUCT OUTPUT

167515 SN0402T0503303.004. *Number of Waste Packages Hit by Igneous Intrusion*. Submittal date: 02/13/2004.

168104 SN0403T0503303.006. *Revised Intermediate Files Associated with Number of Waste Packages Hit by Igneous Intrusion*. Submittal date: 03/09/2004.

ATTACHMENTS

ATTACHMENT I

This attachment describes files and supporting files used in the development of inputs to the DIRECT code, as well as DIRECT output which feeds into a spreadsheet. These data are archived in DTN: SN0403T0503303.006 [168104] *Revised Intermediate Files Associated with Number of Waste Packages Hit by Igneous Intrusion*

file names	Description
RepGeometry.xls	Microsoft Excel spreadsheet. Defines geometry of drifts for eventual inclusion into DIRECT. Extensive annotation within document.
driftData.txt	Input file for DIRECT containing geometric transformation information for each repository emplacement drift
repositorydata.txt	Input file for DIRECT containing geometric information on the perimeter of the repository in the DIRECT coordinate system.
boundingtest1.dts diketest1.dts	Shape files that are read by DIRECT. They are the base shapes that are then extruded and reoriented to represent objects in the scene.
lhs_input1.dat, lhs_input2.dat, lhs_input3.dat	Input file to LHS rename to lhs2_uif$input.dat prior to running on each case.
lhs_1.dat, lhs_2.dat, lhs_3.dat	Renamed output from LHS, provides only the numeric data without any text headings or descriptions. Used by DIRECT.
results_1.txt, results_2.txt, results_3.txt	Renamed output from DIRECT, provides only the numeric data without any text headings or descriptions.

DIRECT files:
Note that for each run of DIRECT, a copy of the corresponding lhs_1.dat, lhs_2.dat, and lhs_3.dat must be first renamed to lhs.dat

In the renamed DIRECT output files, each row stands for a separate realization. The number represents the number of waste packages hit for that case. Note that DIRECT only produces an output file called “results.txt”. The user must rename the file (such as just done here) or the file could get inadvertently overwritten.

Descriptions for RepGeometry.xls
The first worksheet, ‘original’, contains a tabulation of the bounding endpoint coordinates for each repository drift, as well as calculations of drift length (m). This worksheet contains a reference to the source 800-IED-WIS0-00101-000-00Ab [164476].
The second worksheet, ‘scaled down’, contains tabulations of the previous worksheet values scaled down by 100 and translated 1710 m west and 2310 m south. Also, the midpoint of each drift, in these transformed coordinates, is tabulated.

The ‘drift export’ worksheet contains geometric descriptions suitable (following directions) for input to the DIRECT code.
The final worksheet, ‘perimeter’ contains coordinates in transformed DIRECT space, that define a perimeter around the collection of drifts.

Descriptions for lhs_#.dat

line 1 entry 1   realization number, not used
line 1 entry 2   number of sampled variables
line 1 entry 3   concatenation of dike length interval with azimuth angle after decimal point.
line 1 entry 4   number of dikes in the swarm
line 1 entry 5 fraction of the perimeter length at which anchor point is set

The remaining lines (three) in the set are dike spacings, even though all entries may not be used.
This set of 4 lines is repeated (although values change) for each realization.

Description for driftData.txt

Each row defines a single dike or drift
The first three numbers in row represent the x, y, and z coordinates, respectively of the center of the drift.
The next three numbers in the row represent the scaling to be applied in the x, y, and z directions respectively for the drift.
The final four numbers cover rotations. The first three numbers are logical flags for the x, y, or z axes respectively. The fourth number is rotation in degrees. If any flag is labeled 1 instead of zero, then the drift is rotated clockwise about that axis by the stated number of degrees.
The entire sequence is repeated until all drifts are addressed

Description for dikeData.txt

The first row has a single entry, N, defining the number of dikes for the first realization.
The second row has two sets of x, y, and z coordinates (in 'game engine' space) which define the two endpoints of the anchor extension line (see Figure 3).
The next N lines each contain the standard game engine format of data to define each dike.

> The first three numbers represent the x, y, and z coordinates, respectively of the center of the dike.
> The next three numbers represent the scaling to be applied in the x, y, and z directions respectively for the dike.
> The final four numbers cover rotations. The first three numbers are logical flags for the x, y, or z axes respectively. The fourth number is rotation in degrees. If any flag is labeled 1 instead of zero, then the dike is rotated clockwise about that axis by the stated number of degrees.

The entire sequence is repeated until all realizations are addressed

Description for repositorydata.txt

The first row has a single entry, listing the number of rows that follow.
The remaining rows contain the x and y coordinate of a vertex in the repository outline perimeter polygon used. The last row repeats the first x-y coordinate row, to define a closed polygon.

LHS files:

INPUT FILE:
The input data file uses keywords starting in the first column of a line to identify the line or lines of data for each block of input data. The input file starts with two lines of title information with the keyword TITLE at the start of each line. The title information is followed by the number of samples or observations following the keyword NOBS. The fourth line of input is a seed for the random number generator following the keywords RANDOM SEED.

The probability distributions follow the first four lines of input. Each distribution type is identified by one of the following keywords:
BETA, EXPONENTIAL, LOGNORMAL, LOGSTUDENT, LOGUNIFORM, NORMAL, RAYLEIGH, RAYLEXP, STUDENT, TRIANGULAR, UNIFORM, or
USER DISTRIBUTION.

The distribution type is followed by two words that uniquely identify the variable. A distribution is sampled by choosing NOBS values from NOBS equally-sized intervals for the cumulative probability distribution. Each sampled value is chosen randomly from within each interval.

The first distribution used for DIRECT is the joint probability distribution of the dike lengths and azimuths. The distribution is a "USER DISTRIBUTION" and the variable name is DIKE LENAZIM. The second line of the USER DISTRIBUTION gives the number of data points (2218), whether the probability data is equally spaced ("EQUAL" and therefore not listed or specified individually for each line of data ("SPECIFIED"), and whether the distribution is discrete ("DISCRETE") or continuous (CONTINUOUS").
For a discrete distribution, only the specified values are possible sampled values. For a continuous distribution all values between the starting and ending values are possible sampled values. For the DIKE LENAZIM distribution, each length, azimuth pair has its own specified probability (SPECIFIED) and there is no interpolation allowed between these values (DISCRETE). Because LHS allows only one value followed by its probability, the dike length and azimuth are combined into one value using the length as the whole number part of the value and the angle in degrees divided by 1000 as the fraction part of the value. Since "DISCRETE" is specified, no interpolation is allowed and the length and azimuth can be recovered without change from the sampled value. For example, if the value chosen in one of the NOBS intervals is 500.160, the dike length is 500 meters and the dike angle is 160 degrees. Since the length value is actually the start of a 50-meter interval, 25 meters is added to the length inside of DIRECT to give the center of the 50-meter interval. The azimuth angles is the start of a 5 degree interval, so 2.5 degrees is added to the azimuth inside of DIRECT.

The second sampled variable is the number of dikes. The distribution is identified by the line "USER DISTRIBUTION DIKE COUNT". The dike count distribution consists of 18 specified, discrete values of dike count and probability. The distribution is a lognormal distribution with mean 3 that has been truncated to integer values between 1 and 18 and renormalized. The standard deviation of the distribution is chosen so that the 95 percentile point falls at 6 dikes. The median dike count remains 3 after the renormalization. The sampling usually produces one maximum dike count of 13 or 14 in 1000 sample values.

The third distribution is a uniform distribution for the anchor point position. The distribution is identified by the line "UNIFORM ANCHOR POINT". The following line indicates that the uniform distribution is between 0 and 1. The sampled value represents the fraction of the 11302-meter repository perimeter at which the anchor point falls.

The next 13 distributions give the spacings of the dikes. Since the three samplings used for DIRECT have at most 14 dikes, 13 spacings are needed. The first spacing distribution is identified by the line "UNIFORM DIKE SPACING1". The final spacing distribution is identified by the line "UNIFORM DIKE SPACING13". The second line of each distribution indicates that the spacing is sampled uniformly on the interval 100 to 690 meters.

The distributions are followed by a line of output options, started by the keyword OUTPUT. The three output options specified are CORR (correlations), HIST (histograms), and DATA (sampled data listings). The correlation output gives rank correlations of the sampled variables. The rank correlations range from –1 to 1, and values near zero (typically between –0.2 and 0.2) indicate that the grouping of sampled variables show no strong rank correlations. Strong rank correlations would indicate that the sampled variables are not really independent and at least one of them should not be used.

The LHS input data ends with a repetition of the two title lines.

OUTPUT DATA:
The DBG output file (renamed in this attachment to lhs_#.dat) contains the following data for each of the NOBS sampled sets: a sequence number (1 to 1000 for the DIRECT data), the number of sampled variables (16), the LENAZIM value, the dike count, the anchor point perimeter fraction, and 13 dike spacings. These values are read by DIRECT to generate the dike configurations for the igneous intrusions.

ATTACHMENT II

This attachment lists files associated with outputs from the DIRECT code, and the overall effort. These files are archived in DTN:SN0402T0503303.004 [167515] *Updated Number of Waste Packages Hit by Igneous Intrusion*.

Microsoft EXCEL spreadsheet:

ANL-MGR-GS-000003_results.xls

Also, three folders, graphs_set1, graphs_set2, and graphs_set3, each containing a set of 1,000 .png graphics files corresponding to each case.
Those folders are compressed as graphs_set1.zip, graphs_set2.zip, graphs_set3.zip, respectively.

This spreadsheet references the following sources:

DTN: LA0311DK831811.001 [166301]
DTN: LA0307BY831811.001 [164713]

Mishra, S. 2002. *Assigning Probability Distributions to Input Parameters of Performance Assessment Models.* SKB TR-02-11. Stockholm, Sweden: Svensk Kärnbränsleförsörjning A.B. TIC: 252794. [163603]

ATTACHMENT III

This attachment lists only files associated with Section 6.5 of this report. These files are archived in DTN# SN0403T0503303.006 [168104]. *Revised Intermediate Files associated with Number of Waste Packages Hit by Igneous Intrusion.*

ANL-MGR-GS-000003_analysis_REV00I.xls

ANL-MGR-GS-000003_analysis_REV00I_Sensitivity.xls

Collectively, these two spreadsheets reference the following sources:

IED: 800-IED-WIS0-00102-000-00Ab [164490]
IED: 800-IED-WIS0-00103-000-00Ab [164491]
IED: 800-IED-WIS0-00202-000-00B [167207]

DTN: LA0311DK831811.001 [166301]
DTN: LA0302BY831811.001 [162670]

BSC (Bechtel SAIC Company) 2003. *Characterize Eruptive Processes at Yucca Mountain, Nevada.* ANL-MGR-GS-000002 REV 01. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031218.0003. [166407]

ATTACHMENT IV

The information provided by this analysis report addresses the number of waste packages that could be impacted by volcanic conduits or contacted by magma were a basaltic dike to intersect the repository at Yucca Mountain. The analyses documented in this report assume that a dike intersects the repository; hence the analysis provides conditional probabilities, as probability distribution functions, for the number of waste packages hit by igneous intrusion and the number of waste packages that are impacted by eruptive conduits.

The outputs of this analysis are used to describe the source term for TSPA-LA analyses related to the igneous activity volcanic (direct) release and intrusion-groundwater (indirect) release scenarios. The analyses do not address the amount of damage to waste packages or contents. Of specific interest are the number of waste packages that could be damaged as a result of (1) the intrusion of a basaltic dike into one or more repository drifts, or (2) the eruption of a small basaltic volcano through the repository resulting in intersection of waste packages by volcanic conduits.

Yucca Mountain Review Plan Criteria Assessment

The NRC (NRC 2003 [163274]) has identified two integrated subissues that are at least partially addressed by information in this report, Mechanical Disruption of Engineered Barriers and Volcanic Disruption of Waste Packages.

The Yucca Mountain Review Plan (YMRP) (NRC 2003)[163274] provides the review methods and acceptance criteria that the NRC staff will use to evaluate the technical adequacy of the License Application. Although not clearly described in the YMRP, the Integrated Issue Resolution Status Report (NUREG-1762, NRC, 2002) [159538] specifically notes (Section 3.3.10.1, paragraph 1) “Interactions between basaltic magma and waste packages not located along a subvolcanic conduit to the surface are evaluated in the Mechanical Disruption of Engineered Barriers Integrated Subissue” (Section 2.2.1.3.2).

Integrated Subissue: Mechanical Disruption of Engineered Barriers

The following description identifies information from this report that addresses YMRP acceptance criteria and/or review methods related to the integrated subissue of mechanical disruption of engineered barriers (NRC 2003, Section 2.2.1.3.2.3) [163274].

Acceptance Criterion 1: System description and model integration are adequate

The objectives for calculating the number of waste package hit are described in Section 6.1 of the analysis report. The purpose of the analysis and integration of the analysis into TSPA-LA is described in Section 1. In short, this analysis develops a probabilistic measure of the number of waste packages that could be affected by a basaltic igneous event in each of the two TSPA-LA igneous activity scenarios.

(1) Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the mechanical disruption of engineered barrier abstraction process.

This analysis describes the number of drifts intersected by a dike or swarm of dikes. Consequently, through a direct relationship of drifts and numbers of waste packages per drift, this analysis also estimates the number of waste packages contacted by magma in the indirect release scenario. Similarly, for the direct release scenario, the numbers and diameters of conduits that could form within the repository are used to estimate the number of waste packages that would be damaged to the extent that they would provide no further protection for the waste.

The primary geologic and geometric elements used in the analysis (the volcanic dike(s) and any conduits, and the repository layout) are identified and summarized in Sections 6.3 through 6.4. Assumptions about the treatment of waste packages in drifts intersected by a dike and in drifts not directly intersected are described in Section 5.1. An assumption about constant conduit diameters used in the analysis is described in Section 5.2, and assumptions about the number of waste packages damaged by a volcanic conduit are described in Section 5.3. The assumption about the parallelism of dikes is described in section 5.4. The number of waste packages damaged by an igneous intrusion are described in Section 6.3 and summarized in Figure 16. The number of waste packages hit by volcanic eruption are described in Section 6.4 and summarized in Figure 18. Results of the analysis are summarized in Section 7.1, and conclusions are presented in Section 7.2. The principal output of the analysis are CDFs for the number of waste packages hit by an igneous intrusion and by an eruptive conduit. The DTN outputs are referenced in Section 8.5.

It is important to note that this analysis provides only the number of waste packages damaged by igneous intrusion into the repository or by development of one or more eruptive conduits through the reposition. The analysis does not address the nature and extent of damage to waste packages; that assessment is provided in a model report, *Igneous Intrusion Impacts on Waste Package and Waste Form* (BSC 2003 [165002]).

(2) The description of geological and engineering aspects of design features, physical phenomena, and couplings, that may affect mechanical disruption of engineered barriers, is adequate. For example, the description may include materials used in the construction of engineered barrier components, environmental effects (e.g., temperature, water chemistry, humidity, radiation, etc.) on these materials, and mechanical failure processes and concomitant failure criteria used to assess the performance capabilities of these materials. Conditions and assumptions in the abstraction of mechanical disruption of engineered barriers are readily identified and consistent with the body of data presented in the description.

The primary geologic and geometric elements used in the analysis (the volcanic dike(s) and any conduits, and the repository layout) are identified and summarized in Sections 6.3

through 6.4. Assumptions about the treatment of waste packages in drifts intersected by a dike and in drifts not directly intersected are described in Section 5.1. An assumption about constant conduit diameters used in the analysis is described in Section 5.2, and assumptions about the number of waste packages damaged by a volcanic conduit are described in Section 5.3. The assumption about the parallelism of dikes is described in section 5.4.

This analysis provides the number of waste packages damaged by igneous intrusion into the repository or by development of one or more eruptive conduits through the reposition. The analysis does not address the nature and extent of damage to waste packages or environmental conditions that might affect the extent of damage. The assessment of waste package damage and identification of environmental parameters used in the damage analysis are provided in a model report, *Igneous Intrusion Impacts on Waste Package and Waste Form* (BSC 2003 [165002]).

(3) The abstraction of mechanical disruption of engineered barriers uses assumptions, technical bases, data, and models that are appropriate and consistent with other related U.S. Department of Energy abstractions. For example, assumptions used for mechanical disruption of engineered barriers are consistent with the abstraction of degradation of engineered barriers (Section 2.2.1.3.1 of the Yucca Mountain Review Plan). The descriptions and technical bases provide transparent and traceable support for the abstraction of mechanical disruption of engineered barriers.

The outputs from this analysis report are identified in Section 8.5 and consist of CDFs for the number of waste packages hit by igneous intrusion (Figure 16) and by volcanic conduits (Figure 18). Assumptions used in the analysis are described in Section 5. Assumptions about the treatment of waste packages in drifts intersected by a dike and in drifts not intersected by a dike are described in Section 5.1. An assumption about constant conduit diameters is described in Section 5.2. Assumptions about the number of waste packages damaged by a volcanic conduit are described in Section 5.3. The assumption about the parallelism of dikes is described in section 5.4. Section 6.3 describes the analysis of the number of waste packages hit by igneous intrusion, and Section 6.4 describes the analysis of the number of waste packages hit by conduits associated with a volcanic eruption through the repository.

(4) Boundary and initial conditions used in the total system performance assessment abstraction of mechanical disruption of engineered barriers are propagated throughout the abstraction approaches.

Geologic and geometric variables affect the consideration of the number of waste package that could be affected by igneous intrusion into the repository or volcanic eruption through the repository. As described in Section 6.3.1, the geologic variables are mostly stochastic parameters that include dike length and orientation, and geometric elements that include locations of geologic features and repository design elements. Methods to propagate the geologic and geometric variables through the analysis of the number of waste packages hit by igneous intrusion are described in Section 6.3.2 and 6.3.3. The alternate analyses considered in this report, including sensitivity and uncertainty studies, are described in Section 6.5.

(5) Sufficient data and technical bases to assess the degree to which features, events, and processes have been included in this abstraction are provided.

Features, events, and processes (FEPs) that are specifically addressed by information in this analysis report are identified in Section 6.2 and Table 3. Table 3 also identifies sections of the report in which disposition of the FEPs are described and includes a summary of the TSPA-LA disposition. Basically, the outputs of the analysis are CDFs for the number of waste packages hit by an igneous intrusion into the repository and included in conduits that develop as results of a volcanic eruption through the repository (Figures 16 and 18, respectively).

(6) The conclusion, with respect to the impact of transient criticality on the integrity of the engineered barriers, is defensible.

This analysis report does not address the impact of transient criticality on the integrity of the engineered barriers.

(7) Guidance in NUREG-1297 and NUREG-1298 (Altman et al. 1988a, b), or other acceptable approaches, is followed.

NUREG-1297 describes the generic technical position with respect to the use of peer reviews on high-level waste repository programs. Peer review was not used in the development of this analysis. NUREG-1298 describes the generic technical position with respect to qualification of existing data. This report does not document the results of qualification of existing data.

Acceptance Criterion 2: Data are sufficient for model justification

(1) Geological and engineering values, used in the license application to evaluate mechanical disruption of engineered barriers, are adequately justified. Adequate descriptions of how the data were used, and appropriately synthesized into the parameters are provided.

Geologic and geometric variables affect the consideration of the number of waste package that could be affected by igneous intrusion into the repository or volcanic eruption through the repository. As described in Section 6.3.1, the geologic variables are mostly stochastic parameters that include dike length and orientation, and geometric elements that include locations of geologic features and repository design elements. Methods to propagate the geologic and geometric variables through the analysis of the number of waste packages hit by igneous intrusion are described in Section 6.3.2 and 6.3.3. The alternate analyses considered in this report, including sensitivity and uncertainty studies, are described in Section 6.5. The outputs of the analysis are CDFs for the number of waste packages hit by an igneous intrusion into the repository and included in conduits that develop as results of a volcanic eruption through the repository (Figures 16 and 18, respectively).

(2) Sufficient data have been collected on the geology of the natural system, engineering materials, and initial manufacturing defects, to establish initial and boundary conditions for the total system performance abstraction of mechanical disruption of engineered barriers.

This analysis uses a restricted set of data about igneous activity parameters (e.g., the probability of a dike intersecting the repository, dike lengths, dike orientations, and the number of volcanic conduits that could form within the repository footprint) derived from studies of igneous activity in the Yucca Mountain Region (e.g., CRWMS M&O 1996 [100116], BSC 2003 [163769]. Data and input parameters used in this analysis are described in Section 4.1 and summarized in Table 1. Table 1 also provides specific references to individual DTNs or IEDs used in the analysis. Assumptions used in the analysis and derived from the data inputs are described in Sections 5.1 through 5.4. Sections 5.1 through 5.4 include specific references to use of the assumptions within the analysis to preserve traceability throughout the analysis and into the abstraction process.

(3) Data on geology of the natural system, engineering materials, and initial manufacturing defects, used in the total system performance assessment abstraction, are based on appropriate techniques. These techniques may include laboratory experiments, site-specific field measurements, natural analog research, and process-level modeling studies. As appropriate, sensitivity or uncertainty analyses used to support the U.S. Department of Energy total system performance assessment abstraction are adequate to determine the possible need for additional data.

This analysis uses a restricted set of data about igneous activity parameters (e.g., the probability of a dike intersecting the repository, dike lengths, dike orientations, and the number of volcanic conduits that could form within the repository footprint) derived from studies of igneous activity in the Yucca Mountain Region (e.g., CRWMS M&O 1996 [100116], BSC 2003 [163769]. Data and input parameters used in this analysis are described in Section 4.1 and summarized in Table 1. Table 1 also provides specific references to individual DTNs or IEDs used in the analysis. Assumptions used in the analysis and derived from the data inputs are described in Sections 5.1 through 5.4. Sections 5.1 through 5.4 include specific references to use of the assumptions within the analysis to preserve traceability throughout the analysis and into the abstraction process.

Consideration of alternatives, with sensitivity and uncertainty studies, that were conducted as part of this analysis are described in Section 6.5. Section 6.5.1 discusses the analysis of an alternate abstraction. Section 6.5.2 discusses the swarm quad abstractions. Section 6.5.3 discusses the modal azimuth angle case and specific studies on alternate igneous intrusion analysis, dike spacing sensitivity, and dike azimuth sensitivity. Conclusions regarding alternate and sensitivity analyses are presented in Section 6.5.4.

(4) Engineered barrier mechanical failure models for disruption events are adequate. For example, these models may consider effects of prolonged exposure to the expected emplacement drift environment, material test results not specifically designed or performed for the Yucca Mountain site, and engineered barrier component fabrication flaws.

This analysis examines the number of waste packages that could be damaged by intersection of the repository by a basaltic volcanic dike or by eruption of a basaltic volcano through the repository (Figures 16 and 18). This analysis does not evaluate failure modes for engineered barrier components or damage that could result from exposure of waste packages and waste forms to magmatic conditions. Assessments of damage to waste packages and waste forms associated with intrusion of a dike into the repository or eruption of a volcano through the repository are provided in the model report, *Igneous Intrusion Impacts on Waste Package and Waste Form* (BSC 2003 [165002]).

Acceptance Criterion 3: Data uncertainty is characterized and propagated through the model abstraction

Data and parameters used for the analysis of magma-waste package and magma-waste form interactions is described in Section 4.1.

(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, reasonably account for uncertainties, and variabilities, and do not result in an under-representation of risk.

This analysis uses a restricted set of data about igneous activity parameters (e.g., the probability of a dike intersecting the repository, dike lengths, dike orientations, and the number of volcanic conduits that could form within the repository footprint) derived from studies of igneous activity in the Yucca Mountain Region (e.g., CRWMS M&O 1996 [100116], BSC 2003 [163769]. Data and input parameters used in this analysis are described in Section 4.1 and summarized in Table 1. Table 1 also provides specific references to individual DTNs or IEDs used in the analysis. Assumptions used in the analysis and derived from the data inputs are described in Sections 5.1 through 5.4. Sections 5.1 through 5.4 include specific references to use of the assumptions within the analysis to preserve traceability throughout the analysis and into the abstraction process.

Consideration of alternatives, with sensitivity and uncertainty studies, that were conducted as part of this analysis are described in Section 6.5. Section 6.5.1 discusses alternate analyses. Section 6.5.2 discusses the swarm quad abstractions. Section 6.5.3 discusses the modal azimuth angle case and specific studies on alternate igneous intrusion analysis, dike spacing sensitivity, and dike azimuth sensitivity. Conclusions regarding alternate and sensitivity analyses are presented in Section 6.5.4.

The representation of risk is a TSPA-LA responsibility. This report describes no results that could be used to evaluate the representation of risk from magma-drift and magma-waste package interactions.

(2) Process-level models used to represent mechanically disruptive events, within the emplacement drifts at the proposed Yucca Mountain repository, are adequate. Parameter values are adequately constrained by Yucca Mountain site data, such that the estimates of mechanically disruptive events on engineered barrier integrity are not underestimated. Parameters within conceptual models for mechanically disruptive events are consistent with the range of characteristics observed at Yucca Mountain.

This analysis examines the number of waste packages that could be damaged by intersection of the repository by a basaltic volcanic dike or by eruption of a basaltic volcano through the repository (Figures 16 and 18). Sources of inputs for the analysis are listed in Table 1. Consistency of parameter values with observed ranges of characteristics (e.g., frequency of intersection of the repository by a basalt dike, dike length and orientation, and the CDF for number of conduits that could form within the repository) are described in the analysis report, *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [163769]. Table 8 presents a mapping of CDF technical product outputs from this report to the results spreadsheet. Table 9 presents a similar mapping for alternative CDF results, and Table 10 presents a mapping of auxiliary CDF outputs for the two previously-identified spreadsheets. This analysis does not evaluate failure modes for engineered barrier components or damage that could result from exposure of waste packages and waste forms to magmatic conditions. Assessments of damage to waste packages and waste forms associated with intrusion of a dike into the repository or eruption of a volcano through the repository are provided in the model report, *Igneous Intrusion Impacts on Waste Package and Waste Form* (BSC 2003 [165002]).

(3) Uncertainty is adequately represented in parameter development for conceptual models, process-level models, and alternative conceptual models considered in developing the assessment abstraction of mechanical disruption of engineered barriers. This may be done either through sensitivity analyses or use of conservative limits.

Uncertainties in the current analysis have been intrinsically accounted for by the nature of the Latin Hypercube approach. Additionally, conservative assumptions have been included to bound uncertainties associated with parameters used in the analysis as described in Section 6.5. Alternate analyses, and sensitivity and uncertainty studies that were included to examine sensitivities to specific parameters are described in Section 6.5, and results of these analyses are described in Section 6.5.4. The alternative analyses examined the swarm quad abstraction (Section 6.5.2), and sensitivity studies examined effects of dike spacing (Section 6.5.3.2) and dike azimuth (Section 6.5.3.3). Consideration of the effects of an alternate abstraction approach is described in Section 6.5.1.

(4) Where sufficient data do not exist, the definition of parameter values and conceptual models is based on appropriate use of expert elicitation, conducted in accordance with NUREG-1563 (Kotra et al, 1996). If other approaches are used, the U.S. Department of Energy adequately justifies their use.

Expert elicitation was not used in the development of the analysis of number of waste packages hit by igneous intrusion into the repository.

Acceptance Criterion 4: Model uncertainty is characterized and propagated through the model abstraction

(1) Alternative modeling approaches of features, events, and processes are considered and are consistent with available data and current scientific understanding, and the results and limitations are appropriately considered in the abstraction.

Features, events and processes that are included in this report are described in Section 6.2 and summarized in Table 3. Table 3 also summarizes the TSPA-LA disposition of each included FEP and includes references to sections of the report in which the TSPA-LA disposition is described. Analysis of alternates and sensitivity and uncertainty analyses are described in Section 6.5. (Also see Acceptance Criterion 3, Item 4.) Consideration of the effects of an alternate abstraction approach is described in Section 6.5.1.

(2) Consideration of conceptual model uncertainty is consistent with available site characterization data, laboratory experiments, field measurements, natural analog information and process-level modeling studies; and the treatment of conceptual model uncertainty does not result in an under-representation of the risk estimate.

Uncertainties in the current analysis have been intrinsically accounted for by the nature of the Latin Hypercube approach. Additionally, conservative assumptions have been included to bound uncertainties associated with parameters used in the analysis as described in Section 6.3.3 and Section 6.5. Also see Acceptance Criterion 3, Item 4. Sensitivity studies examined effects of dike spacing (Section 6.5.3.2) and dike azimuth (Section 6.5.3.3) consistent with parameter distributions reported in the analysis report, *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [163769].

The representation of risk is a TSPA-LA responsibility. This report describes the number of waste packages hit by igneous intrusion into the repository (Figure 16) and eruption of a volcano through the repository (Figure 18). No results that could be used to evaluate the representation of risk from the abstractions for number of waste packages are developed in this report.

(3) Appropriate alternative modeling approaches are investigated that are consistent with available data and current scientific knowledge, and appropriately consider their results and limitations using tests and analyses that are sensitive to the processes modeled.

Analysis of alternates and sensitivity and uncertainty analyses are described in Section 6.5. (Also see Acceptance Criterion 3, Item 4.) Sensitivity studies examined effects of dike spacing (Section 6.5.3.2) and dike azimuth (Section 6.5.3.3) consistent with parameter distributions reported in the analysis report, *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [163769]. Conclusions from the alternate and sensitivity studies are presented in Section 6.5.4.

Acceptance Criterion 5: Model abstraction output is supported by objective comparisons

(1) Models implemented in this total system performance assessment abstraction provide results consistent with output from detailed process-level models and/or empirical observations (laboratory and field testings and/or natural analogs).

The bases for the analysis of number of waste packages damaged by igneous intrusion into the repository or volcanic eruption through the repository are presented in Sections 6.3 and 6.4. The abstraction of the number of waste packages damaged by an intrusion into the repository are presented in Section 6.3.3 and summarized in Figure 16. The analysis of the number of waste packages damaged by a volcanic eruption through the repository are presented in Section 6.4 and summarized in Figure 18. Comparisons with the Site Recommendation results are presented in Section 6.6. Consideration of the effects of an alternate abstraction approach is described in Section 6.5.1.

(2) Outputs of mechanical disruption of engineered barrier abstractions reasonably produce or bound the results of corresponding process-level models, empirical observations, or both.

The outputs of this analysis are distributions for the number of waste packages hit by igneous intrusion (Figure 16) or included in volcanic conduits (Figure 18). Also documented are median numbers of waste packages hit or included. The analyses consider alternatives for dike spacing (Section 6.5.3.2), dike azimuth (Section 6.5.3.3), and number of dikes in a dike swarm (group of associated dikes) as well as alternative analysis methods (e.g., swarm quad method (Section 6.5.2)). Conclusions reflecting these alternatives are provided in Section 6.5.4.

(3) Well-documented procedures, that have been accepted by the scientific community to construct and test the mathematical and numerical models, are used to simulate mechanical disruption of engineered barriers.

The outputs of the abstraction of number of waste packages damaged by igneous intrusion into the repository are presented in Section 6.3.3 and summarized in Figure 16. The analysis of the number of waste packages damaged by a volcanic eruption through the repository are presented in Section 6.4 and summarized in Figure 18. The results are CDFs for the number of waste packages damaged for the intrusion scenario and the volcanic scenario. The results include the assumptions described in Section 5 and analysis inputs for data and parameters described in Section 4.1.Well-documented procedures, that have been accepted by the scientific community to construct and test the mathematical and numerical models are used to simulate mechanical disruption of engineered barriers.

Uncertainties in the current analysis have been intrinsically accounted for by the nature of the Latin Hypercube approach. Additionally, conservative assumptions have been included to bound uncertainties associated with parameters used in the analysis as described in Sections 6.3.3 and 6.5. Analysis of alternates and sensitivity and uncertainty analyses are described in Section 6.5. (Also see Acceptance Criterion 3, Item 4.) Sensitivity studies examined effects of dike spacing (Section 6.5.3.2) and dike azimuth (Section 6.5.3.3) consistent with parameter distributions reported in the analysis report, *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [163769]. Conclusions from the alternate and sensitivity studies are presented in Section 6.5.4.

(4) Sensitivity analyses or bounding analyses are provided to support the total system performance assessment abstraction of mechanical disruption of engineered barriers that cover ranges consistent with site data, field or laboratory experiments and tests, and natural analog research.

The outputs of the abstraction of number of waste packages damaged by igneous intrusion into the repository are presented in Section 6.3.3 and summarized in Figure 16. The analysis of the number of waste packages damaged by a volcanic eruption through the repository are presented in Section 6.4 and summarized in Figure 18. The results are CDFs for the number of waste packages damaged for the intrusion scenario and the volcanic scenario. The results include the assumptions described in Section 5 and analysis inputs for data and parameters described in Section 4.1. In addition, uncertainties in the current analysis have been intrinsically accounted for by the nature of the Latin Hypercube approach. Additionally, conservative assumptions have been included to bound uncertainties associated with parameters used in the analysis as described in Sections 6.3.3 and 6.5.

Integrated Subissue: Volcanic Disruption of Waste Packages

The following information addresses *Yucca Mountain Review Plan* (NRC 2003 [163274]) acceptance criteria related to volcanic disruption of waste packages (Section 2.2.1.3.10.3).

Acceptance Criterion 1: System Description and Model Integration Are Adequate

(1) Total system performance assessment adequately incorporates important design features, physical phenomena, and couplings, and uses consistent and appropriate assumptions throughout the volcanic disruption of waste package abstraction process.

The intersection of one or more repository drifts by a basaltic dike and subsequent damage to waste packages by magma or by inclusion in a volcanic conduit are coupled processes whose characteristics depend on the nature of the processes that are associated with the intersection and subsequent evolution of the magma-drift system. This analysis describes the number of drifts intersected by a dike and the number of waste packages contacted by magma in the indirect release scenario. Similarly, for the direct release scenario, the number of conduits that could form within the repository are used to estimate the number of waste packages that would be damaged to the extent that they would provide no further protection for the waste. The results of these analyses are presented in Sections 6.3 and 6.4. The methods used to propagate uncertainties in the number and diameter of conduits are described in Section 6.4. Assumptions supporting the analysis are described in Section 5.2 through 5.4. The uses of information from this analysis, in terms of FEPs disposition, by subsequent analyses are summarized in Table 3.

This analyses incorporates design features as documented in Table 1, and reflects the analyses and models used as input and with companion analysis reports and model reports, including the *Characterize Framework for Igneous Activity* (BSC 20033 [163769]), *Characterize Eruptive Processes* (BSC 2003 [166407]), and *Dike Drift Interactions* (BSC 2004 [167778]). This analysis also provides the source term for the igneous groundwater transport model implemented in TSPA (BSC 2003 [167651]) and *Atmospheric Dispersal and Deposition of Tephra from a Potential Volcanic Eruption at Yucca Mountain, Nevada* (BSC 2004 [167616]).

(2) Models used to assess volcanic disruption of waste packages are consistent with physical processes generally interpreted from igneous features in the Yucca Mountain region and/or observed at active igneous systems.

No models were used in the analysis documented in this report. However, the analyses used to develop parameters for TSPA is related to this criterion. The analyses documented in this report are limited to estimating the number of waste packages included in eruptive conduits (direct release scenario) or contacted by magma (indirect release scenario). These analyses do not examine waste package damage caused by, or damage processes related to, volcanic disruption of the repository. Models that assess damage to waste packages and waste forms are documented in a model report, *Igneous Intrusion Impacts on Waste Package and Waste Form* (BSC 2003 [165002]). Other pertinent physical processes are assessed in *Characterize Eruptive Processes* (BSC 2003 [166407]), and the processes are investigated in *Dike Drift Interaction* (BSC 2004 [167778]). Igneous features in the Yucca Mountain region and/or observed at active igneous systems considered in these other disruptive event analyses or model reports support the features included in this analyses (Section 6.3 and 6.4).

(3) Models account for changes in igneous processes that may occur from interactions with engineered repository systems.

This report provides CDFs for the number of waste packages damaged by igneous intrusion into the repository (Figure 16) and volcanic eruption through the repository (Figure 18). The report does not consider changes in igneous processes that could result from interactions with engineered repository systems. Models of the interactions between a basalt dike(s) and the engineered repository system are documented in *Dike-Drift Interaction* (BSC 2004 [167778]) and in the model report, *Igneous Intrusion Impacts on Waste Package and Waste Form* (BSC 2003 [165002]). Results of these models support this analysis.

(4) Guidance in NUREG-1297 and NUREG-1298 (Altman et al. 1988 a and b [103597], [103750]) or other acceptable approaches is followed.

Guidance in NUREG-1297 and NUREG-1298 is not applicable to this analysis. NUREG-1297 describes the generic technical position with respect to the use of peer reviews on high-level waste repository programs. Peer review was not used in the development of this analysis. NUREG-1298 describes the generic technical position with respect to qualification of existing data. This report does not document the results of qualification of existing data.

Acceptance Criterion 2: Data Are Sufficient for Model Justification

(1) Parameter values used in the license application to evaluate volcanic disruption of waste packages are sufficient and adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.

This analysis derives parameters that are sampled as direct feeds to the TSPA (Section 6.3 and 6.4). Design features and developed parameters based on analog data are identified in Table 1. Data used in the analysis are described and justified, and the bases for the values are documented in the references cited in this report (Sections 4.1, 6.3, 6.4).

(2) Data used to model processes affecting volcanic disruption of waste packages are derived from appropriate techniques. These techniques may include site-specific field measurements, natural analog investigations, and laboratory experiments.

The analysis of the number of waste packages hit does not include any modeling of processes affecting volcanic disruption of waste packages. Upstream analyses provide inputs for this analysis, and the bases for the values used in this analysis are documented in the references cited in this report (Sections 4.1, 6.3, 6.4).

(3) Sufficient data are available to integrate features, events, and processes, relevant to volcanic disruption of waste packages into process-level models, including determination of appropriate interrelationships and parameter correlations.

Features, events, and processes related to this analysis and included in TSPA-LA are identified in Table 3 and Section 6.2.

(4) Where sufficient data do not exist, the definition of parameter values and associated conceptual models is based on appropriate use of expert elicitation, conducted in accordance with NUREG-1563 (Kotra et al., 1996) [100909]. If other approaches are used, the U.S. Department of Energy adequately justifies their use.

Expert elicitation was not used in the development of the analysis of number of waste packages hit by igneous intrusion into the repository or volcanic eruption through the repository. Use of the results of the Probabilistic Volcanic Hazard Analysis expert elicitation to characterize data uncertainties are described below, under Acceptance Criterion 3, Item 3.

Acceptance Criterion 3: Data Uncertainty Is Characterized and Propagated Through the Model Abstraction

(1) Models use parameter values, assumed ranges, probability distributions, and bounding assumptions that are technically defensible, and reasonably account for uncertainties and variabilities, and do not result in an under-representation of the risk estimate.

The data, parameter values, assumed ranges, and probability distributions that are used as inputs for this analysis are identified in Section 4.1 and Table 1. Justifications for the use of the various forms of input information are provided in Sections 6.3 and 6.4. The bases for the values are documented in the references cited in this report.

(2) Parameter uncertainty accounts quantitatively for the uncertainty in parameter values observed in site data and the available literature (i.e., data precision), and the uncertainty in abstracting parameter values to process-level models (i.e., data accuracy).

Methods to include uncertainties in the various input parameters needed for this analysis are described in Sections 6.3, 6.4, and Section 6.5. The technical bases for the input values are provided in the documents that have been cited in this analysis report. Outputs of the analysis are described in terms of cumulative distribution functions (Figures 16 and 18) and/or conditional probabilities that capture the uncertainties associated with the parameters.

(3) Where sufficient data do not exist the definition of parameter values and associated uncertainty is based on appropriate use of expert elicitation conducted in accordance with

NUREG-1563 (Kotra et al. 1996 [100909]). If other approaches are used, the U. S. Department of Energy adequately justifies their use.

Expert elicitation was not used in the development of the analysis of number of waste packages hit by igneous intrusion into the repository or volcanic eruption through the repository. However, expert elicitation results were documented in the analysis report, *Characterize Framework for Igneous Activity at Yucca Mountain, Nevada* (BSC 2003 [163769], which was used to provide relevant inputs to the current analysis. Examples of inputs from BSC 2003 [163769] that were used in this analysis include distributions for dike length, orientation, and number of conduits.

Acceptance Criterion 4: Model Uncertainty Is Characterized and Propagated Through The Model Abstraction

Parameter distributions developed in this analysis are utilized in TSPA to propagate epistemic uncertainty related to input parameter distributions. Disruptive event models used to analyze interactions between a basalt dike(s) and engineered repository systems are documented in the *Dike/Drift Interaction* (BSC 2004 [167778]) and in the model report, *Igneous Intrusion Impacts on Waste Package and Waste Form* (BSC 2003 [165002]).

Acceptance Criterion 5: Model Abstraction Output Is Supported by Objective Comparisons

The analysis documented in this report provides the number of waste packages that could be included in volcanic conduits (Section 6.4 and Figure 18) or contacted by magma were a basaltic dike to intersect the repository at Yucca Mountain (Section 6.3.3 and Figure 16).

Models used to analyze interactions between a basalt dike(s) and engineered repository systems are documented in the update of the *Dike Drift Interaction* (BSC 2004 [167778]) and in the model report, *Igneous Intrusion Impacts on Waste Package and Waste Form* (BSC 2003 [165002]).